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THERMAL EXPANSION
Nonmetallic Solids

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VOLUME 13

THERMAL EXPANSION

Nonmetallic Solids

THERMOPHYSICAL PROPERTIES OF MATTER

The TPRC Data Series

A Comprehensive Compilation of Data by the
Thermophysical Properties Research Center (TPRC), Purdue University

Y. S. Touloukian, Series Editor
C. Y. Ho, Series Technical Editor

Volume 1. Thermal Conductivity—Metallic Elements and Alloys
Volume 2. Thermal Conductivity—Nonmetallic Solids
Volume 3. Thermal Conductivity—Nonmetallic Liquids and Gases
Volume 4. Specific Heat—Metallic Elements and Alloys
Volume 5. Specific Heat—Nonmetallic Solids
Volume 6. Specific Heat—Nonmetallic Liquids and Gases (and Supplement)
Volume 7. Thermal Radiative Properties—Metallic Elements and Alloys
Volume 8. Thermal Radiative Properties—Nonmetallic Solids
Volume 9. Thermal Radiative Properties—Coatings
Volume 10. Thermal Diffusivity
Volume 11. Viscosity
Volume 12. Thermal Expansion—Metallic Elements and Alloys
Volume 13. Thermal Expansion—Nonmetallic Solids

New data on thermophysical properties are being constantly accumulated at TPRC. Contact TPRC and use its interim updating services for the most current information.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Thermophysical Properties of Matter-The TPRC Data Series--Vol. 13. Thermal Expansion-Nonmetallic Solids		5. TYPE OF REPORT & PERIOD COVERED Data Book (See block 18) 6. PERFORMING ORG. REPORT NUMBER TPRC Data Series/Vol. 13
7. AUTHOR(s) Touloukian, Y.S.: Kirby, R. K; Taylor, E. R. and Lee, T.Y.R.		8. CONTRACT OR GRANT NUMBER(s) DSA 900-76-C-0860
9. PERFORMING ORGANIZATION NAME AND ADDRESS CINDAS/Purdue University 2595 Yeager Road West Lafayette,IN 47906		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Logistics Agency DTIC-AI/Cameron Station Alexandria, VA 22314		12. REPORT DATE 1977 13. NUMBER OF PAGES 1,800
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Army Materials & Mechanics Research Center Attn: DRXMR-P/Arsenal Street Watertown, MA 02172		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES TEPIAC Publication (DTIC Source Code 413571) Limited hard copies on Data Book available from publisher: Plenum Publishing Corp. 227 W. 17th St., New York, NY 10011 Price: $155/copy. Microfiche copy available from DTIC		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) *Thermal linear expansion--*thermophysical properties--*elements--*oxides--*oxide mixtures--*inorganic compounds--*composites--*alloys--alumina--aluminum-oxides--aluminum nitrides--fluorides--bakelite--beryllium oxides--phosphides--tellurides--silicides--carbonates--carbides--carbon--sulfides--cardboard--cellulose acetate--ceramics--cerium compounds--cesium compounds--chromium		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (continue on reverse side) The TPRC Data Series published in 13 volumes plus a Master Index volume constitutes a permanent and valuable contribution to science and technology. This 17,000 page Data Series should form a necessary acquisition to all scientific and technological libraries and laboratories. These volumes contain an enormous amount of data and information for thermophysical properties on more than 5,000 different materials of interest to researchers in government laboratories and the defense industrial establishment. (continue on reverse side)		

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19. KEYWORDS (cont)

compounds--cobalt compounds--composites--copper compounds--cordierite--corundum--diamond--resins--europium compounds--minerals--gallium compounds--glasses--borosilicate glass--corning glass--lime glass-pyrex glass--pyroceram glass--soda lime glass--graphites--hafnium compounds--holmium compounds--indium compounds--iron compounds--krypton--lanthanum compounds--lead compounds--lithium compounds--lutetium compounds--magnesium compounds--mercury compounds--neodymium compounds--nickel compounds--niobium compounds--nylon--plastics--polymers--plutonium compounds--polycarbonate--polyester--polyethylene--mylar--potassium compounds--praseodymium compounds--quartz--rocks--rubber--rubidium compounds--rutile--samarium compounds--scadium compounds--silica--silicon--silicon compounds--silver compounds--sodium compounds--tantalum compounds--teflon--thallium compounds--thorium compounds--tin oxides--titanium compounds--tungsten compounds--uranium compounds--vanadium compounds--water--ytterbium compounds--yttrium compounds--zinc compounds--zircon--zirconium compounds--

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20. ABSTRACT (cont)

Volume 13. 'Thermal Expansion - Nonmetallic Solids,' Touloukian, Y. S., Kirby, R. K., Taylor, R. E., and Lee, T.Y.R., 1786 pp., 1977

Volume 13 in this 14 volume TPRC Data Series covers 11 nonmetallic elements (including 62 varieties of graphite), 61 simple oxides, 76 complex oxides, 48 salts, 140 nonoxide compounds, five groups of ceramics, 11 groups of cermets, 15 kinds of glasses, 60 polymers, and 15 groups of composites. The data for about half of these materials have been critically evaluated, analyzed, and synthesized, and recommended reference values or provisional values are presented together with the original experimental data.

1800 pages, 1977 $155.00 ($186.00 outside US)

THERMOPHYSICAL PROPERTIES OF MATTER

VOLUME 13

THERMAL EXPANSION

Nonmetallic Solids

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IFI/PLENUM • NEW YORK-WASHINGTON

Library of Congress Cataloging in Publication Data

Main entry under title:

Thermal expansion – nonmetallic solids.

(Thermophysical properties of matter; v. 13)
Includes bibliographical references and index.
1. Expansion of solids. 2. Nonmetallic materials – Thermal properties. I. Touloukian, Yeram Sarkis, 1918- II. Title: Nonmetallic solids.
QC173.397.P87 1970 vol. 13 [QC176.8.T4] 536'.08s
ISBN 0-306-67033-X [536'.414] 77-21804

ISBN (13-Volume Set) 0-306-67020-8
ISBN (Volume 13) 0-306-67033-X

Copyright: © 1977, Purdue Research Foundation

IFI/Plenum Data Company is a division of
Plenum Publishing Corporation
227 West 17th Street, New York, N.Y. 10011

Distributed in Europe by Heyden & Son, Ltd.
Spectrum House, Alderton Crescent
London NW4 3XX, England

Printed in the United States of America

"In this work, when it shall be found that much is omitted, let it not be forgotten that much likewise is performed..."

SAMUEL JOHNSON, A.M.

From last paragraph of Preface to his two-volume *Dictionary of the English Language*, Vol. I, page 5, 1755, London, Printed by Strahan.

Foreword

In 1957, the Thermophysical Properties Research Center (TPRC) of Purdue University, under the leadership of its founder, Professor Y. S. Touloukian, began to develop a coordinated experimental, theoretical, and literature review program covering a set of properties of great importance to science and technology. Over the years, this program has grown steadily, producing bibliographies, data compilations and recommendations, experimental measurements, and other output. The series of volumes for which these remarks constitute a foreword is one of these many important products. These volumes are a monumental accomplishment in themselves, requiring for their production the combined knowledge and skills of dozens of dedicated specialists. The Thermophysical Properties Research Center deserves the gratitude of every scientist and engineer who uses these compiled data.

The individual nontechnical citizen of the United States has a stake in this work also, for much of the science and technology that contributes to his well-being relies on the use of these data. Indeed, recognition of this importance is indicated by a mere reading of the list of the financial sponsors of the Thermophysical Properties Research Center; leaders of the technical industry of the United States and agencies of the Federal Government are well represented.

Experimental measurements made in a laboratory have many potential applications. They might be used, for example, to check a theory, or to help design a chemical manufacturing plant, or to compute the characteristics of a heat exchanger in a nuclear power plant. The progress of science and technology demands that results be published in the open literature so that others may use them. Fortunately for progress, the useful data in any single field are not scattered throughout the tens of thousands of technical journals published throughout the world. In most fields, fifty percent of the useful work appears in no more than thirty or forty journals. However, in the case of TPRC, its field is so broad that about 100 journals are required to yield fifty percent. But that other fifty percent! It is scattered through more than 3500 journals and other documents, often items not readily identifiable or obtainable. Over 85,000 references are now in the files.

Thus, the man who wants to use existing data, rather than make new measurements himself, faces a long and costly task if he wants to assure himself that he has found all the relevant results. More often than not, a search for data stops after one or two results are found—or after the searcher decides he has spent enough time looking. Now with the appearance of these volumes, the scientist or engineer who needs these kinds of data can consider himself very fortunate. He has a single source to turn to; thousands of hours of search time will be saved, innumerable repetitions of measurements will be avoided, and several billions of dollars of investment in research work will have been preserved.

However, the task is not ended with the generation of these volumes. A critical evaluation of much of the data is still needed. Why are discrepant results obtained by different experimentalists? What undetected sources of systematic error may affect some or even all measurements? What value can be derived as a "recommended" figure from the various conflicting values that may be reported? These questions are difficult to answer, requiring the most sophisticated judgment of a specialist in the field. While a number of the volumes in this Series do contain critically evaluated and recommended data, these are still in the minority. The data are now being more intensively evaluated by the staff of TPRC as an integral part of the effort of the National Standard Reference Data System (NSRDS). The task of the National Standard Reference Data System is to organize and operate a comprehensive program to prepare compilations of critically evaluated data on the properties of substances. The NSRDS is administered by the National Bureau of Standards under a directive from the Federal Council for Science

and Technology, augmented by special legislation of the Congress of the United States. TPRC is one of the national resources participating in the National Standard Reference Data System in a united effort to satisfy the needs of the technical community for readily accessible, critically evaluated data.

As a representative of the NBS Office of Standard Reference Data, I want to congratulate Professor Touloukian and his colleagues on the accomplishments represented by this Series of reference data books. Scientists and engineers the world over are indebted to them. The task ahead is still an awesome one and I urge the nation's private industries and all concerned Federal agencies to participate in fulfilling this national need of assuring the availability of standard numerical reference data for science and technology.

EDWARD L. BRADY
Associate Director for Information Programs
National Bureau of Standards

Preface

Thermophysical Properties of Matter, the TPRC Data Series, is the culmination of twenty years of pioneering effort of the Thermophysical Properties Research Center (TPRC), one of the operating centers of the Center for Information and Numerical Data Analysis and Synthesis (CINDAS) at Purdue University, in the generation of tables of numerical data for science and technology. It constitutes the restructuring, accompanied by extensive revision and expansion of coverage, of the original *TPRC Data Book*, first released in 1960 in loose-leaf format, 11″ × 17″ in size, and issued in June and December annually in the form of supplements. The original loose-leaf *Data Book* was organized in three volumes: (1) metallic elements and alloys; (2) nonmetallic elements, compounds, and mixtures which are solid at N.T.P., and (3) non-metallic elements, compounds, and mixtures which are liquid or gaseous at N.T.P. Within each volume, each property constituted a chapter.

Because of the vast proportions the *Data Book* began to assume over the years of its growth and the greatly increased effort necessary in its maintenance by the user, it was decided in 1967 to change from the loose-leaf format to a conventional publication. Thus, the December 1966 supplement of the original *Data Book* was the last supplement disseminated by TPRC.

While the manifold physical, logistic, and economic advantages of the bound volume over the loose-leaf oversize format are obvious and welcome to all who have used the unwieldy original volumes, the assumption that this work will no longer be kept on a current basis because of its bound format would not be correct. Fully recognizing the need of many important research and development programs which require the latest available information, TPRC has instituted a *Data Update Plan* enabling the subscriber to inquire, by telephone if necessary, for specific information and receive, in many instances, same-day response on any new data processed or revision of published data since the latest edition. In this context, the TPRC Data Series departs drastically from the conventional handbook and giant multivolume classical works, which are no longer adequate media for the dissemination of numerical data of science and technology without a continuing activity on contemporary coverage. The loose-leaf arrangements of many works fully recognize this fact and attempt to develop a combination of bound volumes and loose-leaf supplement arrangements as the work becomes increasingly large. TPRC's *Data Update Plan* is indeed unique in this sense since it maintains the contents of the TPRC Data Series current and live on a day-to-day basis between editions. In this spirit, I strongly urge all purchasers of these volumes to complete in detail and return the *Volume Registration Certificate* which accompanies each volume in order to assure themselves of the continuous receipt of annual listing of corrigenda during the life of the edition.

The TPRC Data Series consists initially of 13 independent volumes. The first seven volumes were published in 1970, Volumes 8 and 9 in 1972, Volume 10 in 1973, Volumes 11 and 12 in 1975, Supplement to Volume 6 in 1976, and Volume 13 is planned for 1976. The organization of the TPRC Data Series makes each volume a self-contained entity available individually without the need to purchase the entire Series.

The coverage of the specific thermophysical properties represented by this Series constitutes the most comprehensive and authoritative collection of numerical data of its kind for science and technology.

Whenever possible, a uniform format has been used in all volumes, except when variations in presentation were necessitated by the nature of the property or the physical state concerned. In spite of the wealth of data reported in these volumes, it should be recognized that all volumes are not of the same degree of completeness. However, as additional data are processed at TPRC on a continuing basis, subsequent editions will become increasingly more

complete and up to date. Each volume in the Series basically comprises three sections, consisting of a text, the body of numerical data with source references, and a material index.

The aim of the textual material is to provide a complementary or supporting role to the body of numerical data rather than to present a treatise on the subject of the property. The user will find a basic theoretical treatment, a comprehensive presentation of selected works which constitute reviews, or compendia of empirical relations useful in estimation of the property when there exists a paucity of data or when data are completely lacking. Established major experimental techniques are also briefly reviewed.

The body of data is the core of each volume and is presented in both graphical and tabular formats for convenience of the user. Every single point of numerical data is fully referenced as to its original source and no secondary sources of information are used in data extraction. In general, it has not been possible to critically scrutinize all the original data presented in these volumes, except to eliminate perpetuation of gross errors. However, in a significant number of cases, such as for the properties of liquids and gases, the thermal conductivity and thermal diffusivity of all the elements, and the thermal expansion of most materials in all material categories, the task of full evaluation, synthesis, and correlation has been completed. It is hoped that in subsequent editions of this continuing work, not only new information will be reported but the critical evaluation will be extended to increasingly broader classes of materials and properties.

The third and final major section of each volume is the material index. This is the key to the volume, enabling the user to exercise full freedom of access to its contents by any choice of substance name or detailed alloy and mixture composition, trade name, synonym, etc. Of particular interest here is the fact that in the case of those properties which are reported in separate companion volumes, the material index in each of the volumes also reports the contents of the other companion volumes.* The sets of companion volumes are as follows:

Thermal conductivity:	Volumes 1, 2, 3
Specific heat:	Volumes, 4, 5, 6, 6 Supplement
Radiative properties:	Volumes 7, 8, 9
Thermal expansion:	Volumes 12, 13

* For the first edition of the Series, this arrangement was not feasible for Volumes 7, 8, and 12 due to the sequence and the schedule of their publication, and Supplement to Volume 6 carries its own independent material index.

The ultimate aims and functions of TPRC's Data Tables Division are to extract, evaluate, reconcile, correlate, and synthesize all available data for the thermophysical properties of materials with the result of obtaining internally consistent sets of property values, termed the "recommended reference values." In such work, gaps in the data often occur, for ranges of temperature, composition, etc. Whenever feasible, various techniques are used to fill in such missing information, ranging from empirical procedures to detailed theoretical calculations. Such studies are resulting in valuable new estimation methods being developed which have made it possible to estimate values for substances and/or physical conditions presently unmeasured or not amenable to laboratory investigation. Depending on the available information for a particular property and substance, the end product may vary from simple tabulations of isolated values to detailed tabulations with generating equations, plots showing the concordance of the different values, and, in some cases, over a range of parameters presently unexplored in the laboratory.

The TPRC Data Series constitutes a permanent and valuable contribution to science and technology. These constantly growing volumes are invaluable sources of data to engineers and scientists, sources in which a wealth of information heretofore unknown or not readily available has been made accessible. We look forward to continued improvement of both format and contents so that TPRC may serve the scientific and technological community with ever-increasing excellence in the years to come. In this connection, the staff of TPRC is most anxious to receive comments, suggestions, and criticisms from all users of the volumes. An increasing number of colleagues are making available at the earliest possible moment reprints of their papers and reports as well as pertinent information on the more obscure publications. I wish to renew my earnest request that this procedure become a universal practice since it will prove to be most helpful in making TPRC's continuing effort more complete and up to date.

It is indeed a pleasure to acknowledge with gratitude the multisource financial assistance received from over fifty sponsors which has made the continued generation of these tables possible. In particular, I wish to single out the sustained major support received from the Air Force Materials Laboratory–Air Force Systems Command, the Defense Supply Agency, the Office of Standard Reference Data–National Bureau of Standards, and the Office of Advanced Research and Technology–National Aeronautics and Space Administration.

TPRC is indeed proud to have been designated as a National Information Analysis Center for the Department of Defense as well as a component of the National Standard Reference Data System under the cognizance of the National Bureau of Standards.

While the preparation and continued maintenance of this work is the responsibility of TPRC's Data Tables Division, it would not have been possible without the direct input of TPRC's Scientific Documentation Division and, to a lesser degree, the Theoretical and Experimental Research Divisions. The authors of the various volumes are the Senior staff members in responsible charge of the work. It should be clearly understood, however, that many have contributed over the years and their contributions are specifically acknowledged in each volume. I wish to take this opportunity to personally thank those members of the staff, assistant researchers, graduate research assistants, and supporting graphics and technical typing personnel without whose diligent and painstaking efforts this work could not have materialized.

Y. S. TOULOUKIAN

Director
Center for Information and Numerical
Data Analysis and Synthesis
Distinguished Atkins Professor of Engineering

Purdue University
West Lafayette, Indiana
December 1976

Introduction to Volume 13

This volume of *Thermophysical Properties of Matter, The TPRC Data Series*, presents the data and information on the thermal expansion of nonmetallic elements, compounds, and other kinds of solid materials.

The volume comprises three major sections: the front text on *theory, estimation, and measurement* together with its bibliography, the main body of *numerical data* with its references, and the *material index*.

The text material is intended to assume a role complementary to the main body of numerical data, the presentation of which is the primary purpose of this volume. It is felt that a moderately detailed discussion of the theoretical nature of the property under consideration together with an overview of predictive procedures and recognized experimental methods and techniques will be appropriate in a major reference work of this kind. The extensive reference citations given in the text should lead the interested reader to sufficient literature for a more comprehensive study. It is hoped, however, that enough detail is presented for this volume to be self-contained for the practical user.

The main body of the volume consists of the presentation of numerical data compiled over the years in a most comprehensive and meticulous manner. The extraction of all data directly from their original sources ensures freedom from errors of transcription. Furthermore, gross errors appearing in the original source documents have been corrected. The organization and presentation of the data together with other pertinent information on the use of the tables and figures are discussed in detail in the introductory material to the section entitled *Numerical Data*. The materials covered include 11 nonmetallic elements, 23 groups of graphites, 61 of ceramics, 11 groups of cermets, 15 groups of glasses, 60 polymers, and 15 groups of composites. Of these 452 materials and groups of materials, the data for 228 (i.e., 50.4%) have been critically evaluated, analyzed, and synthesized, and recommended reference values or provisional values have been generated and are presented in the volume together with the original experimental data. Such recommended values are those that were considered to be the most probable when assessments were made of the available data and information. It should be realized, however, that these recommended values are not necessarily the final true values and that changes directed toward this end will often become necessary as more data become available. Future editions will contain these changes.

As stated earlier, all data have been obtained from their original sources and each data set is so referenced. TPRC has in its files all data-source documents cited in this volume. Those that cannot readily be obtained elsewhere are available from TPRC in microfiche form.

We wish to gratefully acknowledge that this volume has grown out of activities made possible principally through the support of the Defense Supply Agency (DSA) under the technical monitorship of the Army Materials and Mechanics Research Center (AMMRC). The guidance and support of representatives of the sponsor have been essential to the success of the activities. Particular mention should be made of the understanding support given by Mr. Joseph L. Blu and Mr. Michael Corridore of DSA and Mr. Samuel Valencia and Dr. John J. Burke of AMMRC. Over the years, several assistant researchers and graduate research assistants have contributed to the preparation of this volume for varying periods under the authors' supervision. In chronological order of their association with TPRC, we wish to acknowledge the contributions of Messrs. P. L. Wang, B. M. Whitcomb, S. N. Vo, P. J. Hoshovsky, and M. H. Kung. Furthermore, Dr. P. D. Desai has participated in the preparation of this volume and has made significant contributions to it.

Inherent in the character of this work is the fact that in the preparation of this volume we have drawn

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most heavily upon the scientific literature and feel a debt of gratitude to the authors of the referenced articles. While their often discordant results have caused us much difficulty in reconciling their findings, we consider this to be our challenge and our contribution to negative entropy of information, as an effort is made to create from the randomly distributed data a condensed, more orderly state.

While this volume is primarily intended as a reference work for the designer, researcher, experimentalist, and theoretician, the teacher at the graduate level may also use it as a teaching tool to point out to his students the topography of the state of knowledge on the thermal expansion of nonmetallic solids. We believe there is also much food for reflection by the specialist and the academician concerning the meaning of "original" investigation and its "information content."

The authors and their contributing associates are keenly aware of the possibility of many weaknesses in a work of this scope. We hope that we will not be judged too harshly and that we will receive the benefit of suggestions regarding references omitted, additional material groups needing detailed treatment, improvements in presentation or in recommended values, and most important, any inadvertent errors. If the *Volume Registration Certificate* accompanying this volume is returned, the reader will assure himself of receiving annually a list of corrigenda as possible errors come to our attention.

West Lafayette, Indiana
December 1976

Y. S. TOULOUKIAN
R. K. KIRBY
R. E. TAYLOR
T. Y. R. LEE

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34	Xenon	Xe	170

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† No original-data figure given.

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37	Beryllium Oxide	BeO	195
38	Cadmium Oxide	CdO	205
39	Calcium Oxide	CaO	208
40	Cerium Dioxide	CeO_2	212
41	Chromium Oxide	Cr_2O_3	217
42	Cobalt Oxide	CoO	221
43*	Deuterium Oxide	D_2O	224
44	Dysprosium Oxide	Dy_2O_3	227
45	Erbium Oxide	Er_2O_3	231
46*†	Europium Monoxide	EuO	235
47	*Europium Oxide*	Eu_2O_3	236
48	Gadolinium Oxide	Gd_2O_3	239
49	Germanium Dioxide (Quartz Type)	GeO_2	243
50	Germanium Dioxide (Rutile Type)	GeO_2	247
51	Hafnium Dioxide	HfO_2	251
52	Holmium Oxide	Ho_2O_3	257
53	Hydrogen Oxide	H_2O	261
54	Indium Oxide	In_2O_3	267
55*†	Iridium Dioxide	IrO_2	270
56	Iron Monoxide	FeO	271
57	Iron Oxide	Fe_2O_3	274
58	Triiron Tetraoxide	Fe_3O_4	278
59	Lanthanum Oxide	La_2O_3	282
60	Lutetium Oxide	Lu_2O_3	285
61	Magnesium Oxide	MgO	288
62	Manganese Monoxide	MnO	302
63*	Manganese Dioxide	MnO_2	305
64	Dimanganese Trioxide	Mn_2O_3	308
65	Dimolybdenum Trioxide	Mo_2O_3	311
66	Neodymium Oxide	Nd_2O_3	315
67	Nickel Oxide	NiO	319
68	Diniobium Pentaoxide	Nb_2O_5	323
69	Plutonium Dioxide	PuO_2	331
70	Dipraseodymium Trioxide	Pr_2O_3	336
71*	Praseodymium Oxide	$PrO_{1.83}(Pr_6O_{11})$	339
72	Ruthenium Dioxide	RuO_2	341
73*	Samarium Oxide	Sm_2O_3	344
74	Scandium Oxide	Sc_2O_3	347
75	Silicon Dioxide (Crystalline)	SiO_2	350

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† No original-data figure given.

2. SIMPLE OXIDES (continued)

Figure and/or Table No.	Name	Formula	Page
76	Silicon Dioxide (Fused)	SiO_2	358
77*	Strontium Oxide	SrO	372
78*	Ditantalum Pentaoxide	Ta_2O_5	374
79	Thorium Dioxide	ThO_2	376
80	Thulium Oxide	Tm_2O_3	383
81	Tin Dioxide	SnO_2	386
82*	Titanium Monoxide	TiO	390
83	Titanium Dioxide	TiO_2	392
84	Dititanium Trioxide	Ti_2O_3	398
85	Tungsten Dioxide	WO_2	402
86	Tungsten Trioxide	WO_3	405
87	Uranium Dioxide	UO_2	413
88	Triuranium Octaoxide	U_3O_8	421
89	Tetrauranium Nonaoxide	U_4O_9	426
90*†	Vanadium Dioxide	VO_2	430
91*	Divanadium Pentaoxide	V_2O_5	432
92	Ytterbium Oxide	Yb_2O_3	435
93	Yttrium Oxide	Y_2O_3	438
94	Zinc Oxide	ZnO	444
95	Zirconium Dioxide	ZrO_2	451

3. COMPLEX OXIDES

96	Calcium Aluminum Oxide	$CaO \cdot Al_2O_3$	464
97*†	Calcium Aluminum Oxide	$CaO \cdot 6Al_2O_3$	468
98	Calcium Aluminum Oxide	$3CaO \cdot Al_2O_3$	469
99*†	Calcium Aluminum Oxide	$3CaO \cdot 5Al_2O_3$	473
100*†	Calcium Aluminum Oxide	$5CaO \cdot 3Al_2O_3$	474
101*†	Dysprosium Aluminum Oxide	$Dy_2O_3 \cdot 2Al_2O_3$	475
102*†	Dysprosium Aluminum Oxide	$3Dy_2O_3 \cdot 5Al_2O_3$	476
103*†	Lead Aluminum Oxide	$PbO \cdot Al_2O_3$	478
104	Magnesium Aluminum Oxide	$MgO \cdot Al_2O_3$	479
105*†	Manganese Aluminum Oxide	$MnO \cdot Al_2O_3$	483
106*†	Nickel Aluminum Oxide	$NiO \cdot Al_2O_3$	484
107*†	Zinc Aluminum Oxide	$ZnO \cdot Al_2O_3$	485
108	Magnesium Chromium Oxide	$MgO \cdot Cr_2O_3$	486
109*†	Zirconium Chromium Oxide	$ZrO_2 \cdot Cr_2O_3$	490
110	Lead Germanium Oxide	$2PbO \cdot GeO_2$	491
111*	Lithium Germanium Oxides		494
112*†	Magnesium Germanium Oxide	$2MgO \cdot GeO_2$	497
113*	Potassium Germanium Oxides		498
114*†	Zinc Germanium Oxide	$2ZnO \cdot GeO_2$	500

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† No original-data figure given.

3. COMPLEX OXIDES (continued)

Figure and/or Table No.	Name	Formula	Page
115*†	Calcium Hafnium Oxide	$CaO \cdot HfO_2$	501
116*†	Strontium Hafnium Oxide	$SrO \cdot HfO_2$	502
117	Calcium Iron Oxide	$CaO \cdot Fe_2O_3$	503
118	Calcium Iron Oxide	$2CaO \cdot Fe_2O_3$	506
119*†	Calcium Aluminum Iron Oxide	$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$	509
120	Magnesium Iron Oxide	$MgO \cdot 2FeO$	510
121	Magnesium Iron Oxide	$MgO \cdot Fe_2O_3$	513
122*†	Strontium Lead Oxide	$SrO \cdot PbO_2$	516
123	Calcium Molybdenum Oxide	$CaO \cdot MoO_3$	517
124*†	Gadolinium Molybdenum Oxide	$Gd_2O_3 \cdot 3MoO_3$	520
125*†	Sodium Lanthanum Molybdenum Oxide	$Na_2O \cdot La_2O_3 \cdot 4MoO_3$	521
126	Strontium Molybdenum Oxide	$SrO \cdot MoO_3$	522
127*†	Dysprosium Niobium Oxide	$Dy_2O_3 \cdot Nb_2O_5$	525
128	Lithium Niobium Oxide	$Li_2O \cdot Nb_2O_5$	526
129*†	Magnesium Niobium Oxides		531
130*†	Potassium Niobium Oxide	$K_2O \cdot Nb_2O_5$	532
131*†	Sodium Niobium Oxide	$Na_2O \cdot Nb_2O_5$	533
132*†	Hafnium Tantalum Oxide	$6HfO_2 \cdot Ta_2O_5$	534
133*	Lead Tantalum Oxide	$PbO \cdot Ta_2O_5$	535
134*†	Lead Tantalum Oxide	$2PbO \cdot Ta_2O_5$	537
135*†	Lead Tantalum Oxide	$3PbO \cdot 2Ta_2O_5$	538
136*	Lithium Tantalum Oxide	$Li_2O \cdot Ta_2O_5$	539
137*†	Niobium Tantalum Oxide	$2Nb_2O_5 \cdot Ta_2O_5$	543
138	Potassium Tantalum Oxide	$K_2O \cdot Ta_2O_5$	544
139*†	Barium Tin Oxide	$BaO \cdot SnO_2$	547
140	Aluminum Titanium Oxide	$Al_2O_3 \cdot TiO_2$	548
141	Barium Titanium Oxide	$BaO \cdot TiO_2$	554
142	Barium Titanium Oxides		560
143*†	Cobalt Titanium Oxide	$CoO \cdot TiO_2$	563
144	Lead Titanium Oxide	$PbO \cdot TiO_2$	564
145*†	Magnesium Titanium Oxide	$MgO \cdot 2TiO_2$	567
146*†	Magnesium Titanium Oxide	$2MgO \cdot TiO_2$	568
147*†	Nickel Titanium Oxide	$NiO \cdot TiO_2$	569
148	Strontium Titanium Oxide	$SrO \cdot TiO_2$	570
149*	Zirconium Titanium Oxide	$ZrO_2 \cdot TiO_2$	574
150*†	Aluminum Tungsten Oxide	$2Al_2O_3 \cdot 5WO_3$	576
151*†	Barium Calcium Tungsten Oxide	$2BaO \cdot CaO \cdot WO_3$	577
152*†	Barium Strontium Tungsten Oxide	$2BaO \cdot SrO \cdot WO_3$	578
153	Calcium Tungsten Oxide	$CaO \cdot WO_3$	580
154*†	Calcium Magnesium Tungsten Oxide	$2CaO \cdot MgO \cdot WO_3$	584
155*†	Chromium Tungsten Oxide	$Cr_2O_3 \cdot WO_3$	586
156	Lead Tungsten Oxide	$PbO \cdot WO_3$	587

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3. COMPLEX OXIDES (continued)

Figure and/or Table No.	Name	Formula	Page
157*†	Lead Iron Tungsten Oxide	$3PbO \cdot Fe_2O_3 \cdot WO_3$	590
158*†	Magnesium Lead Tungsten Oxide	$MgO \cdot 2PbO \cdot WO_3$	591
159*†	Sodium Tungsten Oxide	$Na_2O \cdot WO_3$	592
160*†	Zirconium Tungsten Oxide	$ZrO_2 \cdot 2WO_3$	594
161*†	Chromium Vanadium Oxide	$Cr_2O_3 \cdot V_2O_5$	595
162*†	Niobium Vanadium Oxide	$Nb_2O_5 \cdot V_2O_5$	596
163*†	Tantalum Vanadium Oxide	$Ta_2O_5 \cdot V_2O_5$	597
164*†	Zinc Vanadium Oxide	$ZnO \cdot V_2O_5$	598
165*†	Zinc Vanadium Oxide	$2ZnO \cdot V_2O_5$	599
166*†	Zinc Vanadium Oxide	$3ZnO \cdot V_2O_5$	600
167*†	Barium Zirconium Oxide	$BaO \cdot ZrO_2$	601
168*†	Cadmium Zirconium Oxide	$CdO \cdot ZrO_2$	602
169	Calcium Zirconium Oxide	$CaO \cdot ZrO_2$	603
170	Lead Zirconium Oxide	$PbO \cdot ZrO_2$	606
171	Strontium Zirconium Oxide	$SrO \cdot ZrO_2$	611

4. SALTS

172	Ammonium Dihydrogen Arsenate	$NH_4H_2AsO_4$	616
173*†	Gallium Arsenate	$GaAsO_4$	619
174	Potassium Dideuterium Arsenate	KD_2AsO_4	620
175	Potassium Dihydrogen Arsenate	KH_2AsO_4	623
176	Rubidium Dideuterium Arsenate	RbD_2AsO_4	627
177	Rubidium Dihydrogen Arsenate	RbH_2AsO_4	630
178	Sodium Bromate	$NaBrO_3$	633
179	Calcium Carbonate	$CaCO_3$	637
180*†	Cobalt Carbonate	$CoCO_3$	641
181*†	Iron Carbonate	$FeCO_3$	642
182*†	Magnesium Carbonate	$MgCO_3$	643
183	Manganese Carbonate	$MnCO_3$	644
184*†	Nickel Carbonate	$NiCO_3$	647
185	Sodium Chlorate	$NaClO_3$	648
186	Sodium Iodate	$NaIO_4$	652
187*	Silver Nitrate	$AgNO_3$	655
188	Sodium Nitrate	$NaNO_3$	657
189	Sodium Nitrite	$NaNO_2$	661
190	Strontium Nitrate	$Sr(NO_3)_2$	668
191*†	Miscellaneous Nitrates and Nitrites		671
192*†	Lead Phosphates		674
193*	Potassium Dihydrogen Orthophosphate	KH_2PO_4	677
194	Zinc Orthophosphate	$Zn_3(PO_4)_2$	681
195	Zinc Metaphosphate	$Zn(PO_3)_2$	684

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† No original-data figure given.

4. SALTS (continued)

Figure and/or Table No.	Name	Formula	Page
196*†	Zirconium Phosphates		687
197*†	Miscellaneous Phosphates		689
198*†	Potassium Trihydrogen Selenite	$KH_3(SeO_3)_2$	694
199*†	Sodium Trideuterium Selenite	$NaD_3(SeO_3)_2$	697
200*	Sodium Trihydrogen Selenite	$NaH_3(SeO_3)_2$	699
201*†	Aluminum Silicates		703
202*†	Calcium Silicates		705
203*†	Calcium Dialuminum Orthosilicate	$CaAl_2(SiO_4)_2$	707
204*†	Calcium Magnesium Silicates		708
205*†	Cesium Aluminum Metasilicate	$CsAl(SiO_3)_2$	709
206*†	Iron Silicates		710
207*†	Lead Silicates		711
208*†	Lithium Silicates		713
209	Magnesium Metasilicate	$MgSiO_3$	715
210	Magnesium Orthosilicate	Mg_2SiO_4	718
211*	Zinc Orthosilicate	Zn_2SiO_4	722
212*	Zirconium Orthosilicate	$ZrSiO_4$	724
213*†	Miscellaneous Silicates		727
214*†	Cesium Sulfate	Cs_2SO_4	730
215	Lithium Sulfate	Li_2SO_4	731
216*†	Lithium Hydrazinium Sulfate	$Li(N_2H_5)SO_4$	734
217	Potassium Sulfate	K_2SO_4	736
218*†	Rubidium Sulfate	Rb_2SO_4	739
219*	Sodium Sulfate	Na_2SO_4	740

5. NONOXIDE COMPOUNDS

220	Cadmium Arsenide	Cd_3As_2	744
221	Gallium Arsenide	GaAs	747
222*†	Miscellaneous Arsenides		752
223	Erbium Dodecaboride	ErB_{12}	755
224	Hafnium Diboride	HfB_2	758
225	Holmium Dodecaboride	HoB_{12}	763
226	Niobium Diboride	NbB_2	767
227	Tantalum Diboride	TaB_2	772
228	Titanium Diboride	TiB_2	778
229*†	Vanadium Diboride	VB_2	783
230	Zirconium Diboride	ZrB_2	784
231*†	Zirconium Diboride + Molybdenum Disilicide + ΣX_i	$ZrB_2 + MoSi_2 + \Sigma X_i$	790
232	Miscellaneous Dodecaborides		791
233*†	Miscellaneous Borides		796
234	Cesium Bromide	CsBr	801

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† No original-data figure given.

5. NONOXIDE COMPOUNDS (continued)

Figure and/or Table No.	Name	Formula	Page
235*	Lead Bromide	$PbBr_2$	806
236*†	Manganese Bromide Tetrahydrate	$MnBr_2 \cdot 4H_2O$	808
237	Potassium Bromide	KBr	810
238	Rubidium Bromide	RbBr	816
239	Sodium Bromide	NaBr	821
240	Thallium Bromide	TlBr	826
241*	Potassium Bromide + Potassium Chloride	KBr + KCl	830
242*	Rubidium Bromide + Rubidium Chloride	RbBr + RbCl	834
243	Miscellaneous Bromides and Bromide Mixtures		836
244	Tetraboron Carbide	B_4C	840
245	Trichromium Dicarbide	Cr_3C_2	845
246	Hafnium Carbide	HfC	848
247	Dimolybdenum Carbide	Mo_2C	854
248	Niobium Carbide	NbC	858
249	Plutonium Carbide	PuC	866
250	Silicon Carbide	SiC	873
251	Tantalum Carbide	TaC	879
252	Thorium Dicarbide	ThC_2	886
253	Titanium Carbide	TiC	891
254	Tungsten Carbide	WC	898
255	Uranium Monocarbide	UC	902
256*	Uranium Dicarbide	UC_2	910
257	Uranium Sesquicarbide	U_2C_3	913
258*	Uranium Plutonium Carbide	UPuC	917
259	Vanadium Carbide	VC	922
260	Zirconium Carbide	ZrC	926
261*†	Miscellaneous Carbides		935
262*†	Tantalum Carbide + Tungsten Carbide	TaC + WC	940
263*	Thorium Carbide + Uranium Monocarbide	ThC + UC	941
264*	Uranium Monocarbide + Zirconium Carbide	UC + ZrC	943
265	Hafnium Carbide + Carbon	HfC + C	946
266*	Tantalum Carbide + Graphite	TaC + C	951
267*†	Titanium Carbide + Carbon	TiC + C	953
268	Uranium Monocarbide + Carbon	UC + C	954
269	Zirconium Carbide + Carbon	ZrC + C	957
270	Zirconium Carbide + Graphite	ZrC + C	964
271	Ammonia Chloride	NH_4Cl	968
272	Cesium Chloride	CsCl	973
273*	Lead Chloride	$PbCl_2$	977
274	Lithium Chloride	LiCl	979
275	Potassium Chloride	KCl	982
276	Rubidium Chloride	RbCl	990

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† No original-data figure given.

5. NONOXIDE COMPOUNDS (continued)

Figure and/or Table No.	Name	Formula	Page
277	Silver Chloride	AgCl	995
278	Sodium Chloride	NaCl	1000
279*†	Potassium Chloride + Rubidium Cloride	KCl + RbCl	1012
280*†	*Miscellaneous Chlorides*		1013
281	Barium Fluoride	BaF_2	1021
282	Calcium Fluoride	CaF_2	1025
283*	Iron Difluoride	FeF_2	1030
284*	Lanathanum Trifluoride	LaF_3	1032
285*	Lead Fluoride	PbF_2	1034
286	Lithium Fluoride	LiF	1036
287	Magnesium Fluoride	MgF_2	1043
288	*Manganese Fluoride*	MnF_2	1048
289	Nickel Fluoride	NiF_2	1052
290	Potassium Fluoride	KF	1056
291	Sodium Fluoride	NaF	1060
292	Strontium Fluoride	SrF_2	1065
293*	Thallium Monofluoride	TlF	1069
294	Zinc Fluoride	ZnF_2	1071
295*†	Barium Fluoride + Calcium Fluoride	$BaF_2 + CaF_2$	1074
296*†	*Lithium Fluoride + Nickel Fluoride*	$LiF + NiF_2$	1075
297*†	Miscellaneous Fluorides		1076
298	Lithium Hydride and Lithium Deuteride	LiH and LiD	1079
299*	Lutetium Hydride and Lutetium Deuteride	LuH and LuD	1083
300*	Titanium Dihydride and Titanium Dideuteride	TiH_2 and TiD_2	1085
301*†	Titanium Monohydride	TiH	1089
302*†	Vanadium Hydride	VH	1089
303*	Ytterbium Dihydride	YbH_2	1091
304*	*Zirconium Dihydride*	ZrH_2	1093
305	Cesium Iodide	CsI	1098
306	Potassium Iodide	KI	1102
307	Rubidium Iodide	RbI	1109
308*†	Silver Iodide	AgI	1114
309	Sodium Iodide	NaI	1116
310*†	Thallium Iodide	TlI	1121
311*†	Miscellaneous Iodides		1122
312	*Aluminum Nitride*	AlN	1127
313	Boron Nitride	BN	1131
314	Silicon Nitride	Si_3N_4	1140
315	Titanium Nitride	TiN	1147
316	Uranium Mononitride	UN	1152
317	Zirconium Nitride	ZrN	1156
318	Miscellaneous Nitrides		1160

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† *No original-data figure given.*

5. NONOXIDE COMPOUNDS (continued)

Figure and/or Table No.	Name	Formula	Page
319	Boron Phosphide	BP	1165
320	Gallium Phosphide	GaP	1168
321*	Manganese Phosphide	MnP	1172
322	Plutonium Phosphide	PuP	1176
323	Uranium Phosphide	UP	1179
324*†	Miscellaneous Phosphides		1183
325*	Cadmium Selenide	CdSe	1185
326	Zinc Selenide	ZnSe	1187
327*†	Miscellaneous Selenides		1192
328	Trichromium Silicides	Cr_3Si	1195
329	Molybdenum Disilicide	$MoSi_2$	1198
330	Tantalum Silicide	$TaSi_2$	1202
331	Tungsten Disilicide	WSi_2	1205
332	Miscellaneous Silicides		1208
333	Cadmium Sulfide	CdS	1221
334*	Manganese Sulfide	MnS	1225
335*	Plutonium Sulfide	PuS	1227
336	Uranium Sulfide	US	1229
337	Zinc Sulfide	ZnS	1232
338	*Miscellaneous Sulfides*		1237
339	Cadmium Telluride	CdTe	1243
340*	Chromium Telluride	CrTe	1248
341	Lead Telluride	PbTe	1250
342*	Manganese Telluride	MnTe	1253
343	Mercury Telluride	HgTe	1256
344	Tin Telluride	SnTe	1260
345	Zinc Telluride	ZnTe	1265
346*	Miscellaneous Tellurides and Mixtures		1269

6. CERAMICS

347*	Aluminum Oxide + ΣX_i Ceramics	$Al_2O_3 + \Sigma X_i$	1278
348*	Barium Titanium Oxide Ceramic	$BaO \cdot Ti O_2$	1280
349*	Ceramag Ceramics		1283
350	Pyroceram Ceramics		1287
351*	Miscellaneous Ceramics		1291

7. CERMETS

352	Aluminum Oxide + Aluminum	$Al_2O_3 + Al$	1306
353	Aluminum Oxide + Chromium + ΣX_i	$Al_2O_3 + Cr + \Sigma X_i$	1309
354	Beryllium Oxide + Beryllium	BeO + Be	1313

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7. CERMETS (continued)

Figure and/or Table No.	Name	Formula	Page
355*	Hafnium Dioxide + Iron	HfO_2 + Fe	1317
356	Titanium Carbide + Nickel + ΣX_i	TiC + Ni + ΣX_i	1319
357	Tungsten Carbide + Cobalt	WC + Co	1322
358	Uranium Dioxide + Molybdenum	UO_2 + Mo	1326
359*	Uranium Dioxide + Stainless Steel	UO_2 + S.S.	1330
360	Zirconium Dioxide + Titanium	ZrO_2 + Ti	1333
361	Zirconium Dioxide + Zirconium	ZrO_2 + Zr	1337
362*†	Miscellaneous Cermets		1341

8. GLASSES

363*	Arsenic-Selenium Glass	As-Se	1346
364*	Barium Borate Glass	$BaO-B_2O_3$	1349
365*	Boric Oxide Glass	B_2O_3	1352
366*	Borosilicate Glass	$B_2O_3-SiO_2$	1355
367*	Calcium Borate Glass	$CaO-B_2O_3$	1358
368*†	Corning 0080 Glass		1360
369*†	Corning 1173 Glass		1361
370*†	Corning 7570 Glass		1362
371*†	Corning 9606 Glass		1363
372*	Jena Glass		1364
373*†	Lime Glass		1366
374	Pyrex Glass		1369
375*	Sodium Borate Glass	$Na_2O-B_2O_3$	1374
376*	Sodium Silicate Glass	Na_2O-SiO_2	1377
377*	Strontium Borate Glass	$SrO-B_2O_3$	1380

9. POLYMERS

378*†	Poly(Acetyl Triallyl Citrate)	1384
379*†	Polyacrylonitrile	1385
380*	Poly(Acrylonitrile-Butadiene)	1386
381*†	Poly(Allyl Diglycol Carbonate)	1388
382*†	Poly(Allyl Methacrylate)	1389
383*†	Poly(Diallyl Phenylphosphonate)	1390
384*†	Poly(Diallyl Phthalate)	1391
385*†	Poly(Triallyl Citrate)	1392
386*†	Aromatic Polymide	1393
387*	Poly(Butadiene-Styrene)	1394
388*	Poly(Butyl Methacrylate)	1396
389*†	Polyisobutylene	1402
390	Polycarbonate	1403

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† No original-data figure given.

9. POLYMERS (continued)

Figure and/or Table No.	Name	Page
391*†	Cellulose Acetate	1407
392*†	Cellulose Propionate	1408
393	Poly(Chloro Trifluoroethylene)	1409
394*	Poly(Chloro Trifluoroethylene-1, 1-Difluoroethylene)	1413
395*	Poly(Chlorostyrene)	1415
396*†	Poly(N-Decyl Methacrylate)	1418
397	Polyester	1419
398*†	Poly(Ethyl Acrylate)	1423
399*†	Poly(Ethyl Methacrylate)	1424
400	Polyethylene	1427
401*†	Polyethylene Chlorosulfonate	1434
402*†	Polyethylene Glycol Dimethacrylate	1435
403*†	Polytetraethylene Glycol Dimethacrylate	1436
404*	Polyethylene Terephthalate	1437
405*†	Copoly(Ethylene-Propylene)	1440
406*†	Poly(Trifluoro-Chloroethylene)	1442
407	Poly(Tetrafluoroethylene)	1443
408*†	Poly(N-Hexyl Methacrylate)	1453
409*†	Poly(Cyclohexyl Methacrylate)	1455
410*†	Poly(2-Hydroxyethyl Methacrylate)	1456
411*†	Poly(2-Hydroxypropyl Methacrylate)	1458
412*	Copoly(1, 1-Difluoroethylene-Hexa Fluoropropene)	1460
413*	Poly(Pyromellitimide)	1462
414*†	Poly(2-Methoxyethyl Methacrylate)	1464
415*†	Poly(Methyl Acrylate)	1466
416*	Poly(2-Methyl 1, 3-Butadiene-2-Methylpropene)	1468
417	Poly(Methyl Methacrylate)	1470
418*†	Poly(Methyl Pentene)	1475
419*†	Poly(2-Methyl 5-Vinyl Pyridine Acrylonitrile Butadiene)	1476
420*†	Polymethylene	1477
421*	Polyoxymethylene	1478
422*†	Poly(N-Octyl Methacrylate)	1482
423*†	Poly(N-Propyl Methacrylate)	1484
424*†	Polypropylene	1486
425	Polystyrene	1489
426*†	Polyurethane	1494
427*†	Copoly(Vinyl Chloride-Vinyl Acetate)	1495
428*†	Poly(Vinyl Cyclohexene Dioxide)	1496
429*†	Poly(Vinyl Toluene)	1497
430*	Nylon (Miscellaneous)	1498
431	Epoxy Resin	1502
432*†	Phenolic Resin	1509

* Number marked with an asterisk indicates that recommended/provisional/typical values are not reported for this material; for others these values are reported in separate figure and table of the same number followed by the letter R.

† No original-data figure given.

9. POLYMERS (continued)

Figure and/or Table No.	Name	Page
433*†	Polyester Resin	1511
434*†	Resins (Miscellaneous)	1512
435*	Neoprene Rubber	1514
436*	Silicone Rubber	1517
437*†	Rubbers (Miscellaneous)	1520

10. COMPOSITES

438*	Asbestos/Phenolic Resin Composite	1524
439*†	Asbestos/Teflon Composite	1530
440	Boron Fiber/Epoxy Resin Composite	1531
441*	Glass Fabric/Epoxy Resin Composite	1537
442*	Glass Fabric/Polyester Resin Composite	1542
443	Glass Fiber/Epoxy Resin Composite	1547
444*	Glass Fiber/Phenolic Resin Composite	1559
445*†	Glass Fiber/Phenyl Silane Resin Composite	1565
446*†	Glass Fiber/Silicone Resin Composite	1567
447*	Graphite Fabric/Phenolic Resin Composite	1568
448	Graphite Fiber/Carbon Composite	1576
449	Graphite Fiber/Epoxy Resin Composite	1582
450*	Nylon Fabric/Phenolic Resin Composite	1600
451*	Potassium Titanium Oxide Fiber/Epoxy Resin Composite	1605
452*	Silicon Dioxide Fiber/Phenolic Resin Composite	1608

* Number marked with an asterisk indicates that recommended/provisional/typical values are not reported for this material; for others these values are reported in separate figure and table of the same number followed by the letter R.

† No original-data figure given.

Theory, Estimation, and Measurement

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Notation

A	Amplitude of vibration
a	Lattice spacing; Constant
a_i	Empirical constants
B_s	Adiabatic bulk modulus
B_T	Isothermal bulk modulus
B_0	Isothermal bulk modulus at 0 K
B_c	Isothermal bulk modulus of composite
B_d	Isothermal bulk modulus of dispersed material
B_i	Isothermal bulk modulus of ith material
B_{mt}	Isothermal bulk modulus of matrix material
b	Lattice spacing; Constant
C	Empirical constant; Capacitance
C_i	Heat capacity of ith mode
C_p	Heat capacity at constant pressure
C_v	Heat capacity at constant volume
C_{293}	Heat capacity at constant volume at 293 K
c	Lattice spacing
c_0, c_1	Calibration constants
c_i	Elastic constant
D_i	Thickness of ith material
d	Diameter; Separation of lattice planes
d_p	Diameter of pth fringe
E	Young's modulus
E_i	Young's modulus of ith material
E_D	Internal energy
E_{293}	Internal energy at 293 K
E_M	Internal energy at T_M
F	Free energy; Frequency
F_{th}	Free energy of thermal vibrations
f	Focal length of lens
G_c	Shear modulus of composite
G_{mt}	Shear modulus of matrix material
g	Acceleration of free fall
H	Enthalpy of formation
h	Planck's constant; Miller index
k	Boltzmann constant; Constant; Wave number; Miller index
L	Length
L_{293}	Length at 293 K
L_M	Length at T_M
L_R	Length of reference material
L_s	Length of specimen
l	Miller index
m	Mass
N	Number of particles; Order of interference
n	Number of vacancies; Index of refraction
P	Pressure
P_{st}	Static pressure
P_{th}	Thermal pressure
p	pth fringe
Q	Constant
R	Gas constant; Radius of a circle
S	Entropy
S_i	Sound velocity of the ith branch
s	Anharmonicity constant; Entropy of formation; Distance between fringes
s_{ij}	Elastic compliances
T	Temperature
T_M	Temperature at melting point
T_m	Mean temperature
t	Time
V	Volume
V_0	Volume at 0 K
V_{293}	Volume at 293 K
V_M	Volume at T_M
v	Fractional part of order of interference
v_d	Volume fraction of dispersed material
v_i	Volume fraction of ith material
W	Distance
W_{293}	Weight at 293 K
w_i	Weight fraction of the ith component
X	Height of liquid

X_{293} Height of liquid at 293 K
x Position of particle
α Coefficient of linear thermal expansion; Angle between lattice spacings b and c
α_{293} Coefficient of linear thermal expansion at 293 K
α_c Coefficient of linear thermal expansion of composite
α_D Coefficient of linear thermal expansion of dilatometer
α_I Instantaneous coefficient of linear thermal expansion
α_M Mean coefficient of linear thermal expansion from 0 K to T_M
α_a Coefficient of linear thermal expansion of lattice
α_b Coefficient of linear thermal expansion of bulk material
α_d Coefficient of linear thermal expansion of dispersed material
α_i Coefficient of linear thermal expansion of ith material or component
α_m Mean coefficient of linear thermal expansion
α_{mt} Coefficient of linear thermal expansion of matrix material
β Coefficient of thermal expansion; Angle between lattice spacings a and c
β_{293} Coefficient of thermal expansion at 293 K
β_c Coefficient of thermal expansion of composite
β_G Coefficient of thermal expansion of glass bulb
β_M Mean coefficient of thermal expansion from 0 K to T_M
β_m Mean coefficient of thermal expansion
β_s Coefficient of thermal expansion of glass sphere
γ Grüneisen parameter; Angle between lattice spacings a and b
γ_0 Grüneisen parameter at 0 K
γ_i Grüneisen parameter of ith mode or ith branch
γ_i Grüneisen parameter tensor
γ_∞ Grüneisen parameter at high temperatures
θ_D Debye temperature
θ_0 Debye temperature at 0 K
θ Angle of incident rays
λ Wavelength
λ_v Wavelength in vacuum
μ Poisson's ratio
μ_i Poisson's ratio of ith material
ν_0 Frequency of oscillation of a particle
ν_D Debye frequency
ν_i Frequency of ith mode
ρ Density
σ Stress
τ Period of a pendulum
Φ Potential
Φ_0 Potential energy of a lattice including zero point energy
ϕ Angle
ϕ_1, ϕ_2, ϕ_3 Angles between crystallographic translation vectors
Ω Solid angle
ω Angle
ω_i Angle between direction of interest and the principal crystallographic axes

Theory of Thermal Expansion of Solids

1. INTRODUCTION

"From ghoulies and ghosties, and long leggety beasties and things that go bump in the night, Good Lord deliver us" is an old Scottish prayer. Among the things that went "bump in the night" were certainly coats of armor, structural members of buildings, etc., as they cooled off. It is not difficult to visualize the consternation of our forefathers when such items suddenly emitted strange sounds. Modern homes also creak and groan when changing thermal gradients cause stresses due to unequal thermal expansions. The uses of thermal expansion in our daily lives are readily observable—mercury thermometers to indicate temperature, thermostats to control our heating and cooling systems, and even the use of hot water to "loosen" a stuck jar lid. On a hot summer day the effect of thermal expansion would also be readily apparent if not allowed for by the design engineer. To paraphrase a facetious comment that appeared in a small book, *Physics for Fools*, published in Russia in 1908: Bridges, railroad tracks, and concrete sections of highways are always made shorter than they should be since bodies always expand when heated. Even so, after an unusually hot day, newspapers will have photographs of highways that have buckled and drawbridges that have stuck. The importance to technology of accurate knowledge of thermal expansion is readily apparent when one considers the problems associated with high-performance engines, atomic reactors, reentry vehicles and the like.

One of the first scientific problems associated with dimensional changes in solids caused by temperature fluctuations concerned the measurement of time with pendulums. Although the period, τ,* of a pendulum is almost independent of the amplitude, it does critically depend upon its length:

$$\tau = 2\pi\sqrt{L/g} \qquad (1)$$

* See Notation, p. 1a, for meaning of symbols used in text.

For instance, a change in temperature of 10 deg will cause a change in period of about 0.01% if the pendulum is made of brass. It is not surprising, therefore, that some of the first quantitative measurements of thermal expansion were made in order to obtain more accurate clocks. These measurements were made by Petrus van Musschenbrock [1], a professor of astronomy in Utrecht, around 1730. Professor Musschenbrock measured the thermal expansion of iron, steel, copper, brass, tin, and lead. He found that lead expanded the most and iron the least. In his own words, "Therefore it is very proper to make the Rods of Pendulums for Clocks, of Iron: They are not so good of Steel; and much worse of Brass; yet sometimes they are made of Copper, because it is not so liable to rust; but yet, that is wrong."

The reverse situation, that of using the expansion of solids to measure temperatures even above the boiling point of mercury, was described by J. F. Daniell in 1831 [2], and was intended for various industrial applications, including pottery and smelting. Since then, a large amount of information on thermal expansion has been obtained and with advances in technology the quality of the information has improved. A great deal of this information, however, is worthless, or nearly so, because the material was not sufficiently characterized and/or the experiment was not sufficiently documented. In particular, accurate data on well-characterized materials are needed to understand the behavior of alloy and composite systems. Even so, within the past 20 years measurements on thermal expansion have greatly increased our knowledge in areas such as lattice dynamics, electronic and magnetic interactions, thermal defects, and phase transitions.

2. DEFINITIONS

When heat is added to a material so that there is a change in temperature, $T_1 \rightarrow T_2$, there is a corresponding change in volume, $V_1 \rightarrow V_2$. To describe this

change the mean coefficient of volumetric thermal expansion of the material is defined by

$$\beta_m = \frac{V_2 - V_1}{V_1(T_2 - T_1)} \tag{2}$$

The limiting value of this ratio (at constant pressure P) as the temperature changes by a differential amount dT is defined as the true coefficient of volumetric thermal expansion, or just as the coefficient of thermal expansion, i.e.,

$$\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P \tag{3}$$

The thermal expansion of the substance on heating from T_1 to T_2 is often expressed as percent expansion,

$$\frac{100(V_2 - V_1)}{V_1} \quad \text{or} \quad \frac{100\Delta V}{V} \tag{4}$$

The corresponding definitions for the linear (or unidirectional) case are

$$\alpha_m = \frac{L_2 - L_1}{L_1(T_2 - T_1)} \tag{5}$$

$$\alpha = \frac{1}{L}\left(\frac{\partial L}{\partial T}\right)_P \tag{6}$$

and

$$\frac{100(L_2 - L_1)}{L_1} \quad \text{or} \quad \frac{100\Delta L}{L} \tag{7}$$

where L represents the length. If the expansion is determined from measurements of density, ρ, then

$$\beta_m = \frac{\rho_1 - \rho_2}{\rho_2(T_2 - T_1)} \tag{8}$$

and

$$\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_P \tag{9}$$

If the substance is isotropic the coefficient of thermal expansion is equal to three times the coefficient of linear thermal expansion; i.e.,

$$\beta = 3\alpha \tag{10}$$

The same is not strictly true, however, for the mean coefficients, where

$$\beta_m \simeq 3\alpha_m[1 + (T_2 - T_1)\alpha_m] \tag{11}$$

Ordinarily the coefficient of thermal expansion is not measured directly, but it is either calculated directly from consecutive observations of expansion or by differentiating an equation that represents the expansion. Under certain conditions the instantaneous coefficient of linear thermal expansion will satisfactorily represent the true coefficient. The instantaneous coefficient of linear thermal expansion is defined as

$$\alpha_I = \frac{L_2 - L_1}{L_{293}(T_2 - T_1)} \quad \text{at } T_m = \frac{T_2 + T_1}{2} \tag{12}$$

where L_{293} is the length at 293 K. If the expansion over a limited temperature range can be approximated by a polynomial,

$$\frac{L - L_{293}}{L_{293}} = a_0 + a_1 T + a_2 T^2 + a_3 T^3 + \cdots \tag{13}$$

then

$$\alpha_I = a_1 + 2a_2 T_m + a_3(4T_m^2 - T_2 T_1) + \cdots \tag{14}$$

and

$$\alpha = \frac{L_{293}}{L}(a_1 + 2a_2 T_m + 3a_3 T_m^2 + \cdots) \tag{15}$$

From these equations it can be shown that

$$\alpha = \frac{L_{293}}{L}\left[\alpha_I - \frac{a_3}{4}(\Delta T)^2 - \cdots\right] \tag{16}$$

If $L_{293} \simeq L$ and $\Delta T \to 0$, then $\alpha \simeq \alpha_I$. If the expansion can be represented by a quadratic, $a_i = 0$ when $i > 2$ in Eq. (13), large temperature intervals can be used.

The coefficients needed to describe the expansion of crystals with different symmetries [3] are shown in Table I. The principal coefficients (α_1, α_2, and α_3) describe the volume change of the crystal with

$$\beta = \alpha_1 + \alpha_2 + \alpha_3 \tag{17}$$

These coefficients apply to orthogonal directions, but not necessarily those of the crystallographic translation vectors. The remaining coefficients (α_4, α_5, and

Table I. Thermal Expansion Coefficients for Various Crystal Symmetries

Cubic	α_1	α_1	α_1	0	0	0
Hexagonal	α_1	α_1	α_3	0	0	0
Tetragonal	α_1	α_1	α_3	0	0	0
Trigonal	α_1	α_1	α_3	0	0	0
Orthorhombic	α_1	α_2	α_3	0	0	0
Monoclinic	α_1	α_2	α_3	0	α_5	0
Triclinic	α_1	α_2	α_3	α_4	α_5	α_6

α_6) describe the change in shape (but not the symmetry) of the crystal. For example, a monoclinic crystal will change shape during a temperature change even if cut in the crystallographic reference system, but the interaxial angles ϕ_1 and ϕ_3, which are restricted to 90° by the symmetry, will not change.

The expansivity of a single crystal in a given direction is given by

$$\alpha = \sum_{i=1}^{3} \alpha_i \cos^2 \omega_i \tag{18}$$

where ω_i are the angles between the direction in question and the principal crystallographic axes. For hexagonal, tetragonal, and trigonal symmetries this relationship reduces to

$$\alpha = \alpha_1 + (\alpha_3 - \alpha_1) \cos^2 \omega_3 \tag{19}$$

An example of the coefficients for a hexagonal crystal is given in Fig. 1, which shows the relationship between α_1, α_3, and α for ZnO.

3. POTENTIAL WELL–A SIMPLE MODEL

A three-dimensional array of atoms which are free to vibrate about their equilibrium positions is a reasonable model for a solid substance. The heat capacity of this model can be calculated by assuming that the vibrations are harmonic and their energies are quantized. While these assumptions are very successful in calculating the heat capacity of real solids, the vibrations must be assumed to be anharmonic in order to account for thermal expansion.

This can be understood qualitatively by considering the vibrations of a single particle in the asymmetric potential well

$$\Phi = \tfrac{1}{2}Cx^2 - \tfrac{1}{3}sCx^3 \tag{20}$$

An approximate solution of the nonlinear equation of motion

$$m\frac{d^2x}{dt^2} + Cx - sCx^2 = 0 \tag{21}$$

can be shown [4] to be

$$x = A\left(\cos \nu_0 t - \frac{sA}{6}\cos 2\nu_0 t\right) + \frac{sA^2}{2} \tag{22}$$

where A is the amplitude of the motion. Since $\langle \cos \nu_0 t \rangle = \langle \cos 2\nu_0 t \rangle = 0$, the time-average position of the particle is

$$\langle x \rangle = \frac{sA^2}{2} \tag{23}$$

A shift of the average position that is proportional to the anharmonicity constant s has therefore occurred toward the softer side of the potential well (see Fig. 2). According to classical theory, A^2 is proportional to temperature so that the value of $\langle x \rangle$ can represent the thermal expansion of the system and the coefficient of thermal expansion is a constant that is proportional to s. In the case of a harmonic potential where $s = 0$, the average position of the particle does

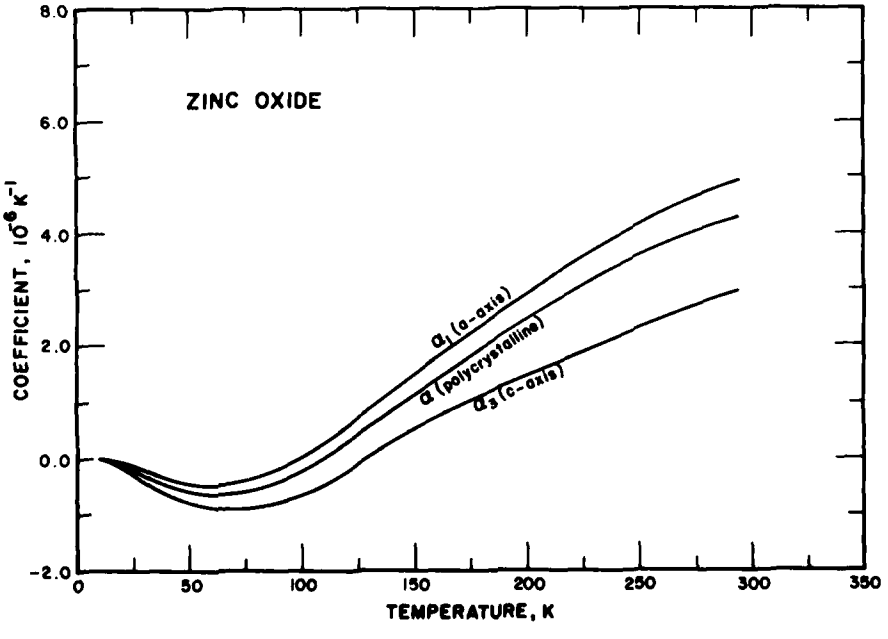


Fig. 1. Thermal expansion coefficients for ZnO illustrating anisotropy.

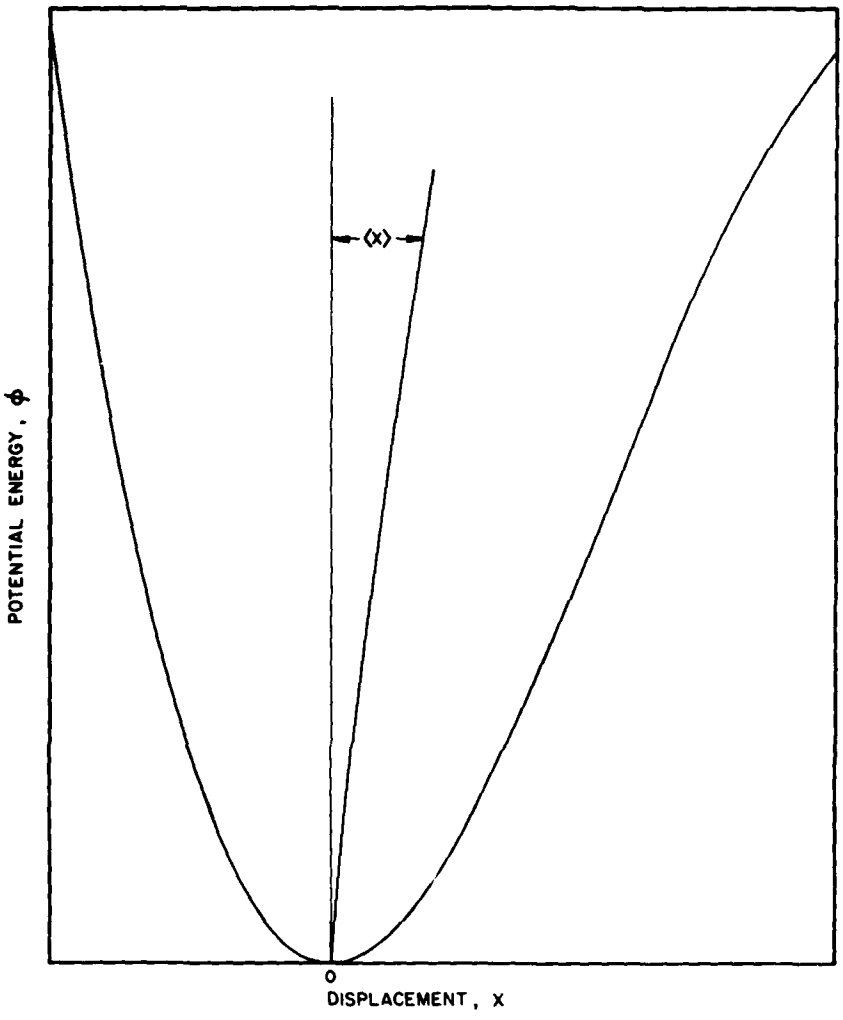


Fig. 2. Plot of asymmetric potential energy well and time-averaged position of vibrating particles.

not shift and there is no corresponding thermal expansion.

4. DERIVATION OF THE GRÜNEISEN RELATION

In the quasi-harmonic approximation the effect of anharmonic interactions is simulated by treating the vibrations as harmonic but with frequencies that are volume-dependent [5]. Applying statistical mechanics to this model it can be shown that

$$\frac{\partial^2 F}{\partial V\,\partial T} = -\frac{1}{V}\sum_{i=1}^{3N} \gamma_i C_i \tag{24}$$

where F is the free energy of the system and C_i is the contribution of the vibrational mode to the heat capacity at constant volume,

$$C_v = \sum_{i=1}^{3N} C_i \tag{25}$$

The quantity γ_i is a measure of the volume dependence of the frequency of the vibrational mode,

$$\gamma_i = -\frac{V}{\nu_i}\frac{d\nu_i}{dV} = -\frac{d\ln \nu_i}{d\ln V} \tag{26}$$

and hence indicates the effect of the anharmonic interactions. If we define

$$\gamma = \frac{\sum_{i=1}^{3N} \gamma_i C_i}{C_v} \tag{27}$$

then

$$\frac{\partial^2 F}{\partial V\,\partial T} = -\frac{\gamma C_v}{V} \tag{28}$$

Since it can also be shown from thermodynamics that

$$\frac{\partial^2 F}{\partial V\,\partial T} = -B_T\beta \tag{29}$$

where B_T is the isothermal bulk modulus, the Grüneisen relation can be obtained:

$$\beta = \frac{\gamma C_v}{VB_T} \tag{30}$$

where γ is known as the Grüneisen parameter.

Since both γ and the product of V and B_T are weak functions of temperature, the value of β is nearly proportional to C_v at all temperatures; that is, at high temperatures β is nearly a constant and at low temperatures, where the atoms must be treated as quantum oscillators, $\beta \to 0$ as $T \to 0$ K.

5. DEBYE EQUATION OF STATE

For many models of a solid one can divide the free energy F into two parts: Φ_0, the effective free energy of the static lattice, including the zero point energy, and F_{th}, the contribution of lattice thermal excitations. One can then define the thermal pressure in a solid to be

$$P_{th} = -\left(\frac{\partial F_{th}}{\partial V}\right)_T \tag{31}$$

and the static pressure to be

$$P_{st} = -\frac{\partial \Phi_0}{\partial V} \tag{32}$$

The total pressure is equal to the sum of these quantities:

$$P = -\frac{\partial \Phi_0}{\partial V} - \left(\frac{\partial F_{th}}{\partial V}\right)_T \tag{33}$$

In Debye's [6] model of a crystal the effect of anharmonic interactions can be expressed as a change of all lattice frequencies ν_i, of the Debye frequency ν_D, and of the characteristic temperature

$$\theta_D = \frac{h\nu_D}{k} \tag{34}$$

proportionally to the same function of volume only. By differentiating Eq. (34) it can be shown with the help of Eq. (26) that

$$\frac{\partial \theta_D}{\partial V} = -\frac{\theta_D \gamma}{V} \tag{35}$$

It follows that in this model γ is also a function of volume only. Since it can also be shown from thermodynamics that

$$\frac{\partial F_{th}}{\partial \theta_D} = \frac{1}{\theta_D}\frac{\partial (F_{th}/T)}{\partial (1/T)} = \frac{E_D}{\theta_D} \tag{36}$$

where E_D is the Debye energy of the lattice vibrations, the Debye equation of state can be obtained:

$$P = -\frac{\partial \Phi_0}{\partial V} - \left(\frac{\partial F_{th}}{\partial \theta_D}\right)\left(\frac{\partial \theta_D}{\partial V}\right) = -\frac{\partial \Phi_0}{\partial V} + \frac{\gamma E_D}{V} \tag{37}$$

Grüneisen's relation can be obtained by differentiating P with respect to temperature at constant volume:

$$\left(\frac{\partial P}{\partial T}\right)_V = \frac{\gamma C_v}{V} = B_T\beta \tag{38}$$

If the pressure is set equal to zero in Eq. (37), $V(\partial\Phi_0/\partial V)$ is expanded in a Taylor series in volume, and the constants of the series evaluated at zero Kelvin, the Grüneisen equation can be obtained [7]:

$$\frac{V_T - V_0}{V_0} = \frac{E_D}{Q - kE_D} \tag{39}$$

where

$$Q = \frac{V_0 B_0}{\gamma} \tag{40}$$

has a value that is large when compared to E_D. The constant k is best determined by experiment but can be related to the potential energy function.

6. GRÜNEISEN PARAMETER

As indicated in Section 4, the Grüneisen parameter, γ, is a weighted average of the γ_i, the weight for each vibrational mode being its contribution to the heat capacity. In the Debye model γ is a function of volume only:

$$\gamma = -\frac{V}{\theta_D}\frac{\partial \theta_D}{\partial V} \tag{41}$$

In a broader sense γ is also a function of temperature, and without assuming that the lattice vibrations are harmonic it can be defined by

$$\gamma(V, T) = \frac{V}{C_v}\left(\frac{\partial S}{\partial V}\right)_T \tag{42}$$

where S is the entropy of the system. By using the Grüneisen relation, $\gamma(V, T)$ can be expressed as

$$\gamma(V, T) = \frac{VB_T\beta}{C_v} = \frac{VB_s\beta}{C_p} \tag{43}$$

where B_s is the adiabatic bulk modulus and C_p is the heat capacity at constant pressure. At temperatures higher than the Debye characteristic temperature θ_D the value of γ is nearly constant, since the whole spectrum of vibrational frequencies is excited and γ_∞ is merely the arithmetic average of the γ_i,

$$\gamma_\infty = \frac{1}{3N}\sum_{i=1}^{3N}\gamma_i \tag{44}$$

In the low-temperature limit the Debye continuum is a valid model, and again γ will approach a constant value,

$$\gamma_0 = -\frac{V}{\theta_0}\frac{d\theta_0}{dV} \tag{45}$$

where θ_0 is the limiting value of θ_D at low temperatures.

If the weightings of γ_i change with temperature the result can be a large variation of γ with temperature, sometimes leading to negative values. This can happen in open-structure crystals, such as silicon between 18 and 120 K [8] (see Fig. 3), when the transverse modes, which can have negative γ_i, outweigh the longitudinal modes, which have positive γ_i. The result is that the coefficient of thermal expansion is also negative and the material will contract on heating. This can be explained by a simple model in which, as the temperature is increased, the average distance between the atoms in a specific direction is increased by their vibration in that direction (longitudinal) but is decreased to a greater extent by their vibrations perpendicular to that direction (transverse).

For solids which have noncubic symmetry, one can define six macroscopic quantities γ_j, components of the Grüneisen tensor, through a generalized Grüneisen relation

$$\alpha_i = \frac{C_p}{V}\sum_{j=1}^{6} s_{ij}\gamma_j \qquad i = 1, 2, 3 \tag{46}$$

where s_{ij} are the elastic compliances [9]. This equation gives a linear relation between components of the expansion tensor and the heat capacity. The coefficient of thermal expansion is the trace of the expansion tensor:

$$\beta = \frac{C_p}{V}\sum_{i=1}^{3}\sum_{j=1}^{6} s_{ij}\gamma_j \tag{47}$$

Where s_{ij} $(j = 4, 5, 6) = 0$, as in cubic, hexagonal, orthorhombic, and some tetragonal crystals, a single value of γ can be determined by

$$\gamma = \sum_{i,j=1}^{3} s_{ij}\gamma_j \Big/ \sum_{i,j}^{3} s_{ij} \tag{48}$$

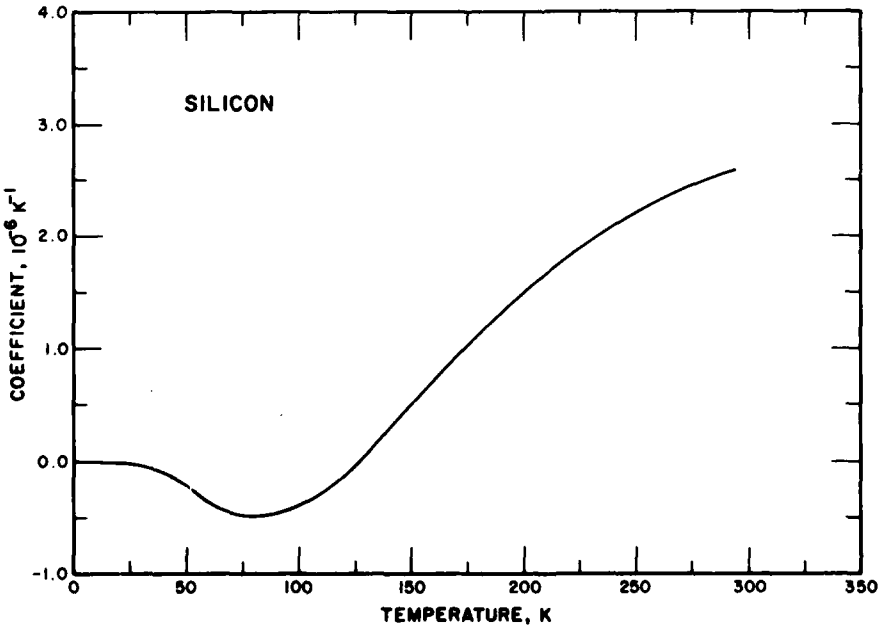


Fig. 3. Thermal expansion coefficients for silicon illustrating negative values.

For hexagonal crystals (see Table I).

$$\alpha_1 = \frac{C_p}{V}[(s_{11}+s_{12})\gamma_1 + s_{13}\gamma_3] \tag{49}$$

$$\alpha_3 = \frac{C_p}{V}[2s_{13}\gamma_1 + s_{33}\gamma_3] \tag{50}$$

$$\beta = \frac{C_p}{V}[2(s_{11}+s_{12}+s_{13})\gamma_1 + (2s_{13}+s_{33})\gamma_3] \tag{51}$$

and

$$\gamma = \frac{2(s_{11}+s_{12}+s_{13})\gamma_1 + (2s_{13}+s_{23})\gamma_3}{2s_{11}+s_{33}+2s_{12}+4s_{13}} \tag{52}$$

In the case of rutile at room temperatures, values of γ_1 and γ_3 of 1.46 and 2.08, respectively, are obtained using Eqs. (49) and (50) and the data given in Table II. Since ν, γ_i, and s_{ij} are relatively temperature-insensitive, the temperature dependence of α_i is mainly controlled by the C_p factor.

In 1958 Sheard [10] applied an anisotropic continuum model to calculate the Grüneisen parameters at low and high temperatures from the pressure dependence of the elastic constants. Assuming that at long wavelengths for each of the three acoustic branches in cubic crystals,

$$\rho S_i^2 = c_i \tag{53}$$

(S_i is the velocity of sound and c_i is the elastic constant) and

$$\nu_i = kS_i \tag{54}$$

where the application of cyclic boundary conditions requires that

$$kL = 0, \pm 1, \pm 2, \ldots, \pm N/2 \tag{55}$$

(k is the wave number and L is the length of the crystal), it can be shown that

$$\gamma_i = -\frac{V}{\nu_i}\frac{d\nu_i}{dV} = \frac{1}{3} + \frac{B_T}{S_i}\frac{dS_i}{dP} = \frac{B_T}{2c_i}\frac{dc_i}{dP} - \frac{1}{6} \tag{56}$$

Table II. Selected Properties of Rutile at Room Temperature

$\alpha_1 = 7.18\times10^{-6}\ K^{-1}$
$\alpha_3 = 9.21\times10^{-6}\ K^{-1}$
$C_p = 56.53\ J\ mol^{-1}\ K^{-1}$
$V = 18.81\ cm^3\ mol^{-1}$
$s_{11} = 6.79\times10^{-8}\ cm^2\ N^{-1}$
$s_{12} = -4.02\times10^{-8}\ cm^2\ N^{-1}$
$s_{13} = -0.80\times10^{-8}\ cm^2\ N^{-1}$
$s_{33} = 2.59\times10^{-8}\ cm^2\ N^{-1}$

Thus, for high temperatures

$$\gamma_\infty = \frac{1}{3N}\sum_i^3 \gamma_i = \frac{1}{12\pi}\sum_i^3 \int \gamma_i\, d\Omega \tag{57}$$

and for low temperatures

$$\gamma_0 = \frac{\sum_i^3 \int \gamma_i S_i^{-3}\, d\Omega}{\sum_i^3 \int S_i^{-3}\, d\Omega} = \frac{\sum_i^3 \int \gamma_i c_i^{-3/2}\, d\Omega}{\sum_i^3 \int c_i^{-3/2}\, d\Omega} \tag{58}$$

where Ω is the solid angle within the Debye sphere. These integrations are usually accomplished by numerical techniques on a computer. It can be seen from Eq. (56) that when the pressure derivative of an elastic constant is sufficiently small or negative, the corresponding γ_i will be negative. If this γ_i also corresponds to a dominant mode (such as the shear or transverse mode at low temperatures) it then can cause the weighted average to be small or negative, with a resulting small or negative coefficient of thermal expansion.

7. SOME SEMIEMPIRICAL RELATIONSHIPS

In Section 4 it was pointed out that the changes of expansivity and heat capacity with temperature are similar and because they are both determined as derivatives of experimental data, mathematical techniques that are used in the computation and analysis of heat capacity are useful in the computation and analysis of expansivity.

The fact that there is a relationship between β and the melting temperature, T_M, for crystalline materials has been known since at least 1879 [11]. For example, the total expansion of the face-centered cubic alkali halides on heating from 0 K to T_M is

$$\frac{V_M - V_0}{V_0} \sim 0.145 \tag{59}$$

This observation leads to the conclusion that the mean coefficient is inversely proportional to the melting temperature since

$$\frac{V_M - V_0}{V_0} = \int_0^{T_M} \beta\, dT = \beta_M \int_0^{T_M} dT = T_M \beta_M \tag{60}$$

where β_M is the mean coefficient of thermal expansion from 0 K to T_M. The corresponding relationship for linear expansion is

$$\frac{L_M - L_0}{L_0} = T_M \alpha_M \sim 0.046 \tag{61}$$

A slightly more useful empirical equation for these alkali halides is

$$T_M\alpha\left(\frac{T_M}{2}\right)\sim 0.047 \tag{62}$$

where $\alpha(T_M/2)$ is the coefficient of linear thermal expansion at half the melting temperature. However, a rule of thumb for crystalline engineering materials with melting temperatures above 2500 K is that these materials will expand about 3% on heating from room temperature to their melting temperature (see Fig. 4) providing no phase change occurs. Notable exceptions to this rule include Al_2O_3 (~1.9%) and MgO (~4%).

A useful relationship for estimating the contraction from room temperature to zero Kelvin can be based on the Grüneisen equation. From Eq. (39) and its derivative we find that

$$\frac{V_{293}-V_0}{V_0}=\frac{E_{293}}{Q-kE_{293}} \tag{63}$$

and

$$\beta_{293}\simeq\frac{QC_{293}}{(Q-kE_{293})^2} \tag{64}$$

Dividing Eq. (63) by Eq. (64), we get

$$\frac{V_{293}-V_0}{V_0\beta_{293}}=\frac{E_{293}(Q-kE_{293})}{QC_{293}} \tag{65}$$

Since $kE_{293}\ll Q$ for most crystalline engineering materials the contraction from 293 to 0 K can be estimated from

$$\frac{V_{293}-V_0}{V_0}=\frac{E(\theta_D/293)}{C(\theta_D/293)}\beta_{293} \tag{66}$$

or

$$\frac{L_{293}-L_0}{L_0}=\frac{E(\theta_D/293)}{C(\theta_D/293)}\alpha_{293} \tag{67}$$

where $E(\theta_D/293)$ and $C(\theta_D/293)$ are the values for energy and heat capacity at 293 K as calculated from the Debye equations [5]. The use of Eq. (67) is illustrated in Table III for a number of materials where θ_D varies by a factor of three.

There is a relationship between index of refraction and thermal expansion coefficient for transmitting materials [12]. This is illustrated in Fig. 5 which is a plot of refractive index n at 1 μm and thermal expansion coefficient at 293 K for the alkali halides. From this plot an empirical relation

$$\alpha=-20.48\times10^{-6}+38.83n \tag{68}$$

is obtained.

The thermal expansion of a multioxide glass can be estimated by assuming that the coefficient of thermal expansion is an additive property. Around room temperature the coefficient is calculated by means of

$$\alpha=\sum a_i w_i \tag{69}$$

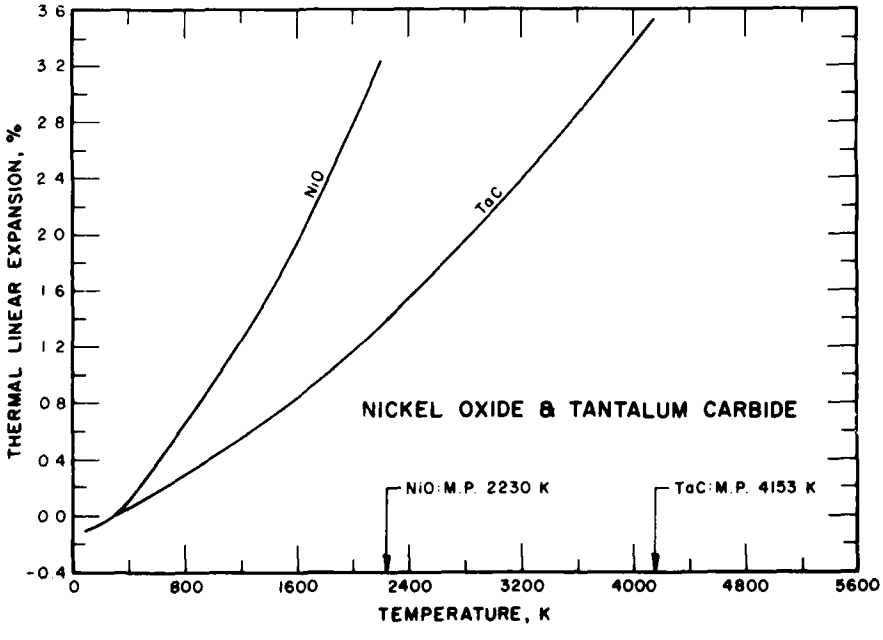


Fig. 4. Thermal expansion of NiO and TaC.

Table III. Comparison of Experimental and Calculated Thermal Expansion Values between 0 and 293 K

	θ_D	$\frac{E(\theta_D/293)}{C_v(\theta_D/293)}$	α_{293}	$\frac{E(\theta_D/293)}{C_v(\theta_D/293)}\alpha_{293}$	(Experimental) $\frac{L_{293}-L_0}{L_0}$	% Difference*
Al_2O_3	1043 K	113 K	5.2×10^{-6} K^{-1}	0.00061	0.00057	3
MgO	946	120	10.4	0.00126	0.00141	11
SiO_2	470	174	11.5	0.00179	0.00200	0
CaF_2	510	167	18.4	0.00317	0.00321	5
NaCl	321	201	39.7	0.00804	0.00776	3

* $\frac{\text{Exp}-\text{Calc}}{\text{Exp}}\times 100.$

Table IV. Calculated Values of the Coefficient of Thermal Expansion of Multioxide Glasses

		Glass A		Glass B	
Oxide	a_i	w_i	α_i	w_i	α_i
SiO_2	0.005	45.6	0.23×10^{-6} K^{-1}	41.2	0.21×10^{-6} K^{-1}
PbO	0.106	45.5	4.82	51.1	5.42
K_2O	0.340	5.7	1.94	6.5	2.21
Na_2O	0.432	2.7	1.17	0.7	0.30
Calculated α			8.16		8.14
Experimental α			8.4		8.3

where every a_i is a constant for each oxide constituent, and w_i is the percentage by weight of the ith oxide. The values of the constant multiplying factors for most of the glass-forming oxides have been determined [13]. An example of the use of Eq. (69) is given in Table IV for two similar glasses. While not exact, this assumption is very useful in determining the effect of compositional changes.

8. PHASE TRANSFORMATIONS, IMPERFECTIONS, AND POINT DEFECTS

First-order transformations in single-phase systems are characterized by a discontinuous change in

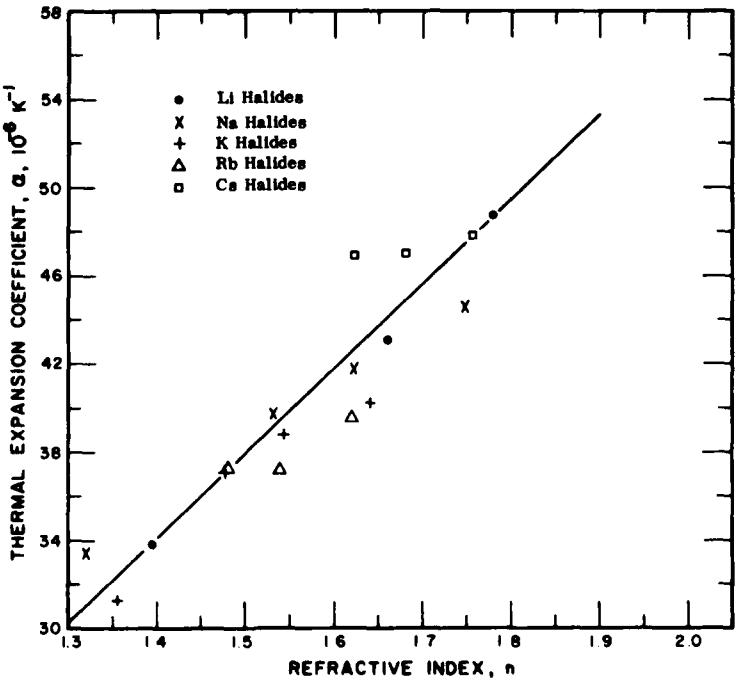


Fig. 5. Thermal expansion coefficient vs refractive index for alkali halides.

volume at constant temperature and pressure. This type of transformation, in which a discontinuous reconstruction of the lattice occurs, includes the change from one crystal structure to another, as in SiO_2 at 846 K, where the change is between two forms of hexagonal structure (see Fig. 6). The change in volume may be large or very small and positive or negative. In multiphase systems the transition may extend over an appreciable temperature range and occur at generally higher temperatures on heating than on cooling.

Second-order transformations are generally characterized by the disappearance of ordered structures, with the result that a discontinuous or abrupt change occurs in the coefficient of thermal expansion at constant temperature and pressure (see Fig. 7). The change in the coefficient may be large or very small and positive or negative. The ordered structures may consist of electric or magnetic moments as in ferroelectric or ferromagnetic materials, or of crystals in the crystalline–glass transition. In polymers the temperature at which translational motion of the molecular chains ceases is called the glass transition temperature. Below this temperature, however, rotation in chain groups may still occur, which leads to additional second-order transitions. The glass transformation in neoprene rubber is shown in Fig. 8 using the data of Weitzel *et al.* [14].

In general the presence of voids in a solid will not significantly affect the expansion since the hole will expand an equal amount. This will not be true, however, if the number of voids changes with temperature. For example, when a material is heated to temperatures close to its melting point a significant number of thermal vacancies, n, are generated,

$$n = Ne^{s/k}e^{-H/kT} \tag{70}$$

where s is the entropy of formation and H is the enthalpy of formation per vacancy. If the vacancy is formed by an atom moving from a lattice site in the interior to a lattice site on the surface (a Schottky defect) the density of the crystal will decrease. Since the dimensions of the crystal lattice at low vacancy concentrations will not be significantly changed, the increase in the vacancy concentration on heating from some sufficiently low temperature can be determined as

$$\frac{n}{N} = 3\left(\frac{\Delta L}{L} - \frac{\Delta a}{a}\right) \tag{71}$$

where a is the lattice parameter as measured with x rays [15]. It follows that

$$\alpha_b - \alpha_a = \frac{nH}{3NkT^2} \tag{72}$$

where α_b is the expansivity of the bulk and α_a is the expansivity of the lattice. In the case of KCl at the melting point $\alpha_b - \alpha_a = 6.3 \times 10^{-6}\ \mathrm{K}^{-1}$.

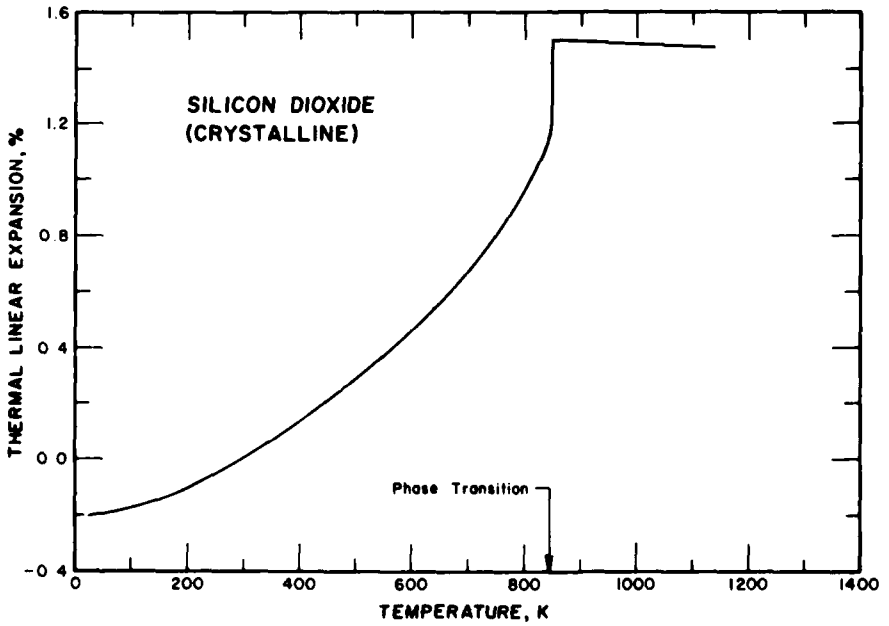


Fig. 6. Thermal expansion of crystalline SiO_2 showing effect of phase transformation.

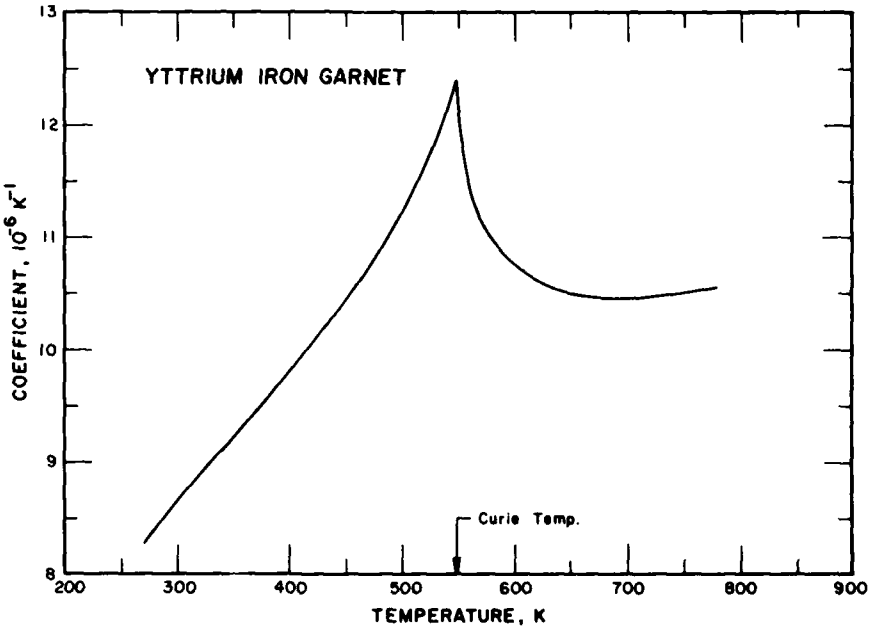


Fig. 7. Coefficient of expansion of yttrium iron garnet showing effect of order–disorder transformation.

9. EFFECTS OF PRESSURE AND STRESS ON EXPANSION

From the definitions of the coefficients of thermal expansion and the bulk modulus it can be shown that the effect of applied pressure on the expansivity of a solid is given by

$$\left(\frac{\partial \beta}{\partial P}\right)_T = \frac{1}{B_T^2}\left(\frac{\partial B_T}{\partial T}\right). \tag{73}$$

Since $(\partial B_T/\partial T)_p$ is negative, the expansivity will

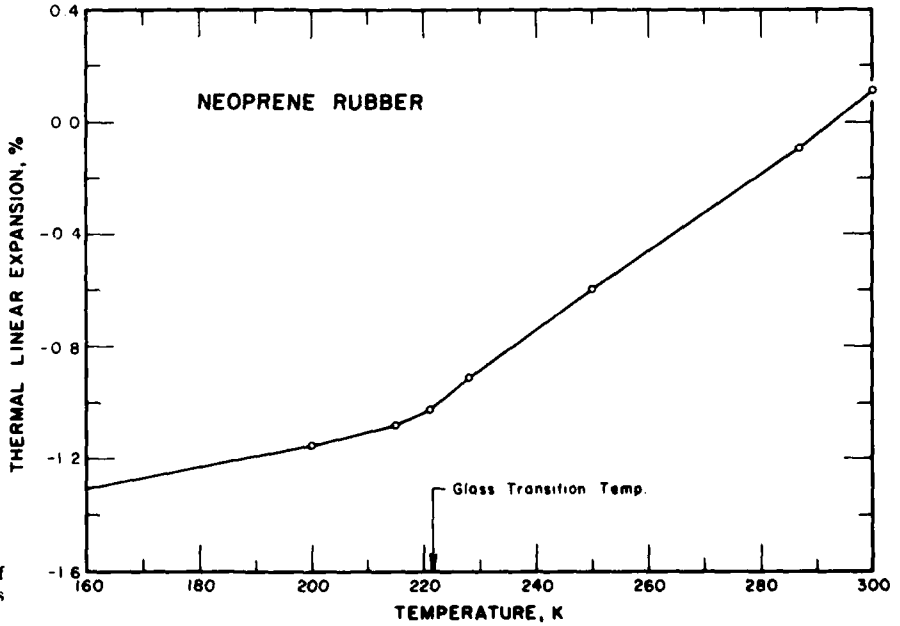


Fig. 8. Thermal expansion of neoprene rubber showing glass transition.

decrease with increasing pressure. The following equation, which can be derived [16] from the Murnaghan equation of state, is very useful for estimating the coefficient of thermal expansion at high pressures:

$$\beta(P, T) = \frac{B_T(0, T)\beta(0, T)}{P(\partial B_T(0, T)/\partial P)_T + B_T(0, T)} \quad (74)$$

The effect of uniaxial stress, σ, on the linear expansivity of a solid [17] is given by

$$\left(\frac{\partial \alpha}{\partial \sigma}\right)_T = -\frac{1}{E^2}\left(\frac{\partial E}{\partial T}\right)_\sigma \quad (75)$$

where E is Young's modulus (the tensile stress is taken as negative). In terms of the bulk modulus and Poisson's ratio, μ, the effect of stress is given by

$$\left(\frac{\partial \alpha}{\partial \sigma}\right)_T = \frac{1}{3B_T(1-2\mu)}\left[\frac{1}{B_T}\left(\frac{\partial B_T}{\partial T}\right)_p - \frac{2}{(1-2\mu)}\left(\frac{\partial \mu}{\partial T}\right)_\sigma\right] \quad (76)$$

10. THERMAL EXPANSION OF COMPOSITES AND MIXTURES

When thermal stresses arise in solids because of differences between the expansion of neighboring grains or substructures the expansion of the composite will be a function of the expansivity and the elastic properties of the individual grains or substructures. In general, the thermal behavior of a composite is a complex function of the thermal and elastic properties of the components but can be predicted by the use of a discrete element method of analysis with the aid of a computer [18]. Many simplified relationships have been derived, however, and some of these are cited here.

In composites where the elastic properties of the components are nearly equal and in mixtures where thermal stresses do not arise, such as in loose powders, the expansivity of the material can be calculated with the simple rule of mixtures.

$$\alpha_c = \sum_i \alpha_i v_i \quad (77)$$

where v_i is the volume fraction of the ith component.

An initially straight two-layerd composite strip will bend and form an arc of a circle when subjected to a temperature change ΔT [19]. The radius of the circle is given by

$$R = \frac{1}{6\,\Delta\alpha\,\Delta T(D_1+D_2)D_1D_2E_1E_2 \times [3(D_1+D_2)^2D_1D_2E_1E_2 + (D_1E_1+D_2E_2)(D_1^3E_1+D_2^3E_2)]} \quad (78)$$

where D_1 and D_2 are the thicknesses of the metal strips. The expansivity of a symmetrical laminate (sandwich) composite in the direction parallel to the layers [20] is

$$\alpha_c = \sum_i \frac{\alpha_i E_i D_i}{1-\mu_i} \Big/ \sum_i \frac{E_i D_i}{1-\mu_i} \quad (79)$$

The expansivity of a composite in which the thermal shear stresses are low, such as some alloys, is given by Turner's formula [21]

$$\alpha_c = \sum_i \alpha_i B_i v_i \Big/ \sum_i B_i v_i \quad (80)$$

According to Kerner [22], a composite made with packed grains, none of which is continuous, will expand according to

$$\alpha_c = \left(\frac{4G_c}{B_c}+3\right)\sum_i \frac{\alpha_i v_i}{(4G_c/B_i)+3} \quad (81)$$

(where G_c is the shear modulus of the composite), while a composite composed of a matrix of one phase in which another phase is dispersed will expand according to

$$\alpha_c = \alpha_{mt} + \frac{(\alpha_d - \alpha_{mt})v_d}{\frac{12B_{mt}G_{mt}}{3B_{mt}+4G_{mt}}\left[\frac{v_d}{3B_{mt}} + \frac{1}{4G_{mt}} + \frac{1-v_d}{3B_d}\right]} \quad (82)$$

A polycrystalline specimen of an element or a compound that is anisotropic can also be considered as a composite material. In this case

$$\beta_c \neq \alpha_1 + \alpha_2 + \alpha_3 \quad (83)$$

However, for crystals with hexagonal symmetry, where Young's modulus E depends on the angle ω_3 with respect to the principal crystallographic axes [3], the expansivity can be approximated by

$$\alpha_c = \frac{\int \alpha E \sin \omega_3\, d\omega_3}{\int E \sin \omega_3\, d\omega_3} \quad (84)$$

All of the approximations for the expansivity of composites depend upon the following assumptions: (1) no voids; (2) no cracking or sintering during a temperature cycle; (3) the thermal strain does not exceed the elastic limit; and (4) no chemical reaction between phases.

11. STRUCTURAL ASPECTS IN CERAMICS AND GLASSES

In general, there does not seem to be a good correlation between crystal structure and thermal expansion. For instance, the various compounds that

have a corundum-type structure as well as those that have a ru ile-type structure do not have similar expansivities. There are a few cases, however, where there does seem to be a correlation. These occur in the spinel family ($MgAl_2O_4$, $MgCr_2O_4$, $FeCr_2O_4$, etc.) and in the group $BeAl_2O_4$, Al_2O_3, and BeO where the oxygen atoms are close packed and the unit dimensions are similar. A close similarity has also been found between the various forms of SiO_2 and $AlPO_4$.

Materials that form glasses usually have a crystalline form characterized by an open structure and a high viscosity melt. A random structure characteristic of the melt can, therefore, be frozen in by rapid cooling. Glasses are said to be in metastable equilibrium relative to the crystalline form. In the range between the melting temperature and the glass transition temperature, T_g, the atomic configuration possesses a degree of randomness which is temperature-dependent. Because the viscosity is changing very rapidly in this range, it is possible to freeze in different configurations (different specific volumes) by varying the rate of cooling or by quenching from different temperatures within that range.

Figure 9 indicates the sort of results that are obtained with borosilicate glass [23]. On fast cooling from above T_g a high volume structure is obtained and on very slow cooling a low volume structure is obtained. On slow heating of the quenched glass it will expand normally to a temperature near T_g, but then its volume will decrease toward that of the fine annealed glass before again expanding. On the other hand, the rapid heating of the fine annealed glass will

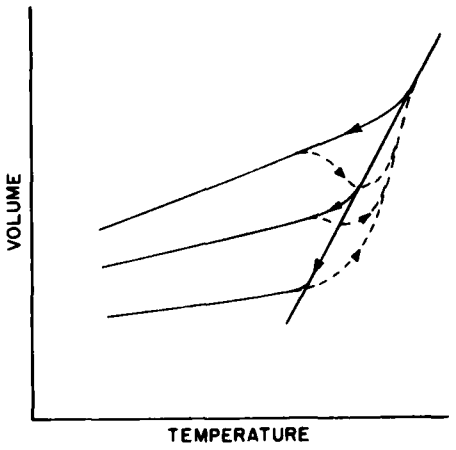


Fig. 9. Volume–temperature diagram for a borosilicate glass.

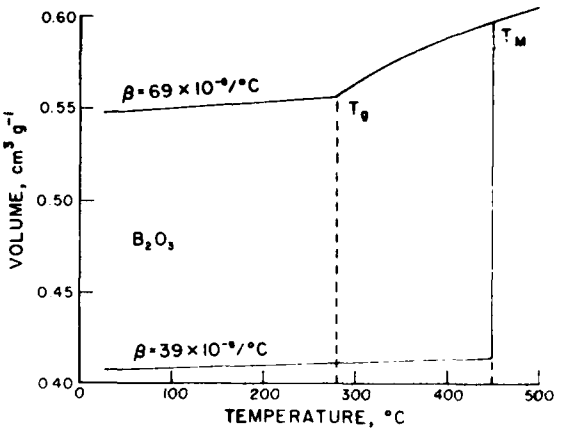


Fig. 10. Volume–temperature diagram for B_2O_3.

carry its low volume structure to temperatures above T_g.

It is expected that a glass characterized by different densities would have different expansivities. Ritland [24] has found this to be the case for borosilicate glasses, as indicated in Fig. 9, and Brueckner [25] has found the same behavior in vitreous silica. Ritland also pointed out that there is a difference between the expansivity of a glass that has been quenched and that of the same glass that has been slowly cooled, even though the same specific volume had been obtained.

In the B_2O_3 system (see Fig. 10) the relationship between the crystalline and glassy states is more or less normal with the glass having the largest expansivity. The situation for SiO_2 is not so clear, however,

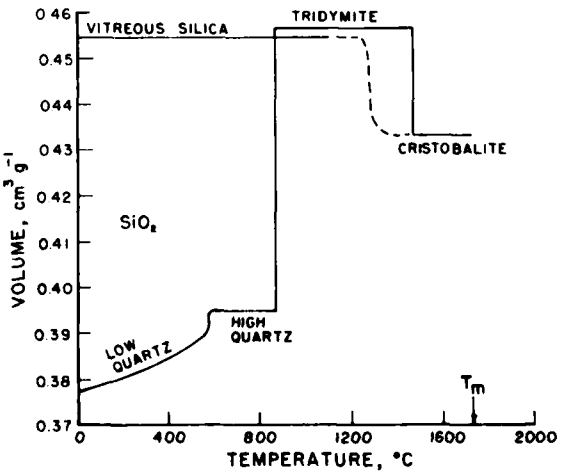


Fig. 11. Volume–temperature diagram for SiO_2.

because of the 22 crystalline phases that can form. It is of interest, however, that all of the stable high-temperature phases have near-zero expansivity and that when silica glass is heated to a high enough temperature it will crystallize in the cristobalite phase(see Fig. 11). Silica is, therefore, normal in that the glassy and crystalline states of the same configuration have about the same expansivity. It is, of course, the near-zero expansivity of vitreous silica that makes it so useful.

Methods for the Measurement of the Thermal Expansion of Solids

1. INTRODUCTION

Many different methods and variations of methods for measuring the thermal expansion of solids have been developed, especially during the past fifty years. A variety of methods are useful for many different reasons. For instance: (1) high accuracy and sensitivity are necessary for measurements at temperatures approaching absolute zero where the coefficient of thermal expansion is very small; (2) at moderate temperatures an industrial application may call for automation and fast response; or (3) a knowledge of the lattice spacings is needed to understand the behavior of an anisotropic material. The choice of method may also depend upon the material to be measured, the amount of material available, the temperature range of the measurement, and the type of information required.

Broadly speaking, all methods for measuring thermal expansion may be divided into two classes: (1) relative methods in which the expansion of the material being investigated is measured relative to the expansion of another material; and (2) absolute methods in which the expansion of the material being investigated is measured directly.

Among early measurements of expansion were those of Musschenbrock [1] in the 18th century. In his apparatus the expansion of a horizontally mounted specimen (about 15 cm in length) was magnified by a simple gear train. Heat was provided by 1, 2, 3, 4, or 5 candles placed beneath the specimen. In 1805, Lavoisier and Laplace [26] used an optical lever for magnification in an improved version of Musschenbrock's apparatus. Ramsden [26] in 1785 used a variation of the twin-telemicroscope (comparator) technique to measure thermal expansion. This technique was further developed by Callendar [27] in 1887 and by Holborn and Day [28] in 1900. Although Fizeau [29] measured the absolute expansion of a reference material that separated the optical flats in his interferometer (a very difficult measurement for him to make), he routinely measured the expansion of specimens relative to that material. Reimerdes [30] in 1896 followed by Scheel [31] in 1902 was among the first to use interferometry to measure thermal expansion in the true absolute sense.

In 1927, Becker [32] successfully used x-rays to measure thermal expansion. This was particularly important because it became possible to directly measure the expansion of anisotropic crystals and to study high-temperature phases. In 1960, White [33] used a highly sensitive capacitance technique at low temperatures to precisely measure thermal expansion. Developments are continuing on methods of measuring thermal expansion with the application of modern technology. Examples are the use of stabilized lasers [34] to obtain sensitivities of 10^{-9} in expansion measurements and the use of computer-controlled data acquisition systems to measure a specimen during a rapid temperature change [35].

In the sections that follow, the major methods are briefly described. For finer details of experimental design and technique, the reader is referred to the references given for the individual methods.

2. PUSH-ROD DILATOMETERS

The push-rod dilatometer method for measuring thermal expansion is experimentally simple (see Fig. 12), reliable, and easy to automate [36]. With this method, the expansion of the specimen is transferred out of the heated zone to an extensometer by means of rods (or tubes) of some stable material. The expansion of the specimen is given by

$$\frac{\Delta L}{L_{293}} = c_0 \frac{(\Delta L)_a}{L_{293}} + c_1 \qquad (85)$$

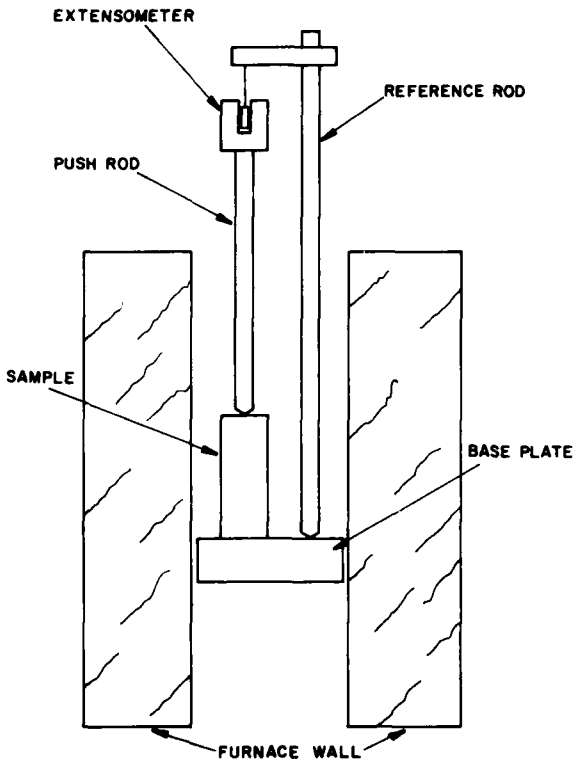


Fig. 12. Schematic diagram of push-rod dilatometer.

where $(\Delta L)_a$ is the apparent change in length as calculated from the difference between the extensometer readings at two different temperatures, and c_0 and c_1 are calibration constants for the system. If the reference rod is made the same length as the push rod and a second specimen placed on the base plate, the dilatometer will measure the difference between the specimens [37]. The difference, or differential expansion, is given by

$$\frac{(\Delta L)_2}{L_{293}} - \frac{(\Delta L)_1}{L_{293}} = c_0 \frac{(\Delta L)_a}{L_{293}} + c_1 \qquad (86)$$

When used this way the dilatometer can have a very high sensitivity. This technique is also very useful for quality control measurements and for studying phase transitions.

In the Baudran [38] or scissors dilatometer, the expansion of a specimen is sensed by rods that penetrate the hot zone in a direction perpendicular to the specimen axis instead of in line with it (see Fig. 13). Because the expansion of the rods does not add to the expansion of the specimen, the measurement is absolute.

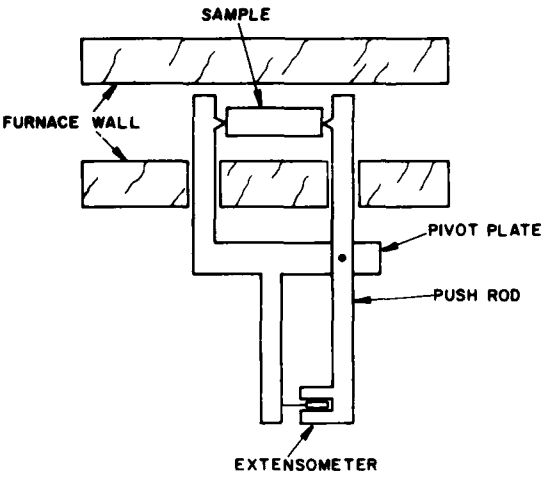


Fig. 13. Schematic diagram for Baudran dilatometer.

One of the most common sources of error in using dilatometers is the measurement of temperature. All too often the temperature that is measured is not the temperature of the specimen. This is especially true in measurements made while the temperature is changing. If a thermocouple is used, care must be taken to ensure that its junction and the specimen are the same temperature; they can be at different temperatures even if in contact with each other.

Another common source of error, especially for flexible materials or materials near their softening temperature, is deformation under the load of the push rod. Special techniques such as increasing sample diameter, reducing push rod pressure, and using horizontal mounts must be used for these soft materials.

Not only should the extensometer and thermometer be very carefully calibrated but care should be taken to avoid any drift in the calibration. If the calibrations are accurate, the value of c_0 in Eq. (85) is equal to 1. If the push rod and the reference rod in the usual type of dilatometer expand exactly the same, c_1 is the expansion of that part of the reference rod that is equal in length to the specimen. In the differential or Baudran dilatometer c_1 should be equal to zero. In normal usage, however, c_0 and c_1 will be found to vary from their ideal values. A single reference material of known expansion can be used to determine the value of c_1, or two or more reference materials can be used to determine the values of both c_0 and c_1 [39]. It can be shown that the latter method is better except when the expansion of a reference material is within two percent of that of the test material.

When used at temperatures below 1200 K dilatometers are usually made of vitreous silica [40]. For use at higher temperatures they are made of alumina [41] silicon carbide [42], tantalum [43], and other refractory materials. Linear variable differential transformers [36] are most frequently used for measuring expansion, but many other types of extensometers have been used. These include dial gauges [40], optical levers [44], microscopes [45], optical gratings [46], interferometers [47], and micrometers [48].

3. TWIN-TELEMICROSCOPE METHOD

The twin-telemicroscope method is most useful for measuring the absolute expansion of large specimens at high temperatures. The best results with this method are obtained when the two microscopes are rigidly mounted to a bar of low-expansion material and the length change measured with filar micrometer eyepieces [49]. Telemicroscopes (microscopes with a relay lens) are needed because of the large working distance imposed by the furnace (over 15 cm) and the necessity for a magnification of at least 500× to obtain measurements with a sensitivity of 1 μm. In the temperature range below 1200 K fiducial marks may be cut into or indented into flat surfaces machined on the specimen [50]. Above 1200 K the gauge length is best defined by knife edges machined into the specimen in such a way that they will form sharp images [51]. Both knife edges should face the same direction (see Fig. 14), so that vaporization or changes in lighting conditions will not affect the measurements. Small clean holes drilled through a thin section of the specimen are also satisfactory [52].

The furnace windows may cause significant errors in length measurements if both surfaces are not flat. An argon atmosphere is sometimes necessary to keep the windows clean, especially if an optical pyrometer is used to measure temperature. When an atmosphere is used, however, care must be taken to avoid sight paths that pass through nonperpendicular temperature gradients [52]. Each microscope should be separately calibrated and positioned on the supporting bar so that its plane of focus coincides with that of the other. Because of the large sample size, an effort should be made to provide either a sufficiently large constant temperature zone or a zone with a known temperature gradient [53].

4. INTERFEROMETERS

These methods are based on the interference of monochromic light reflected from two surfaces [54] that are separated by a specimen or by the combina-

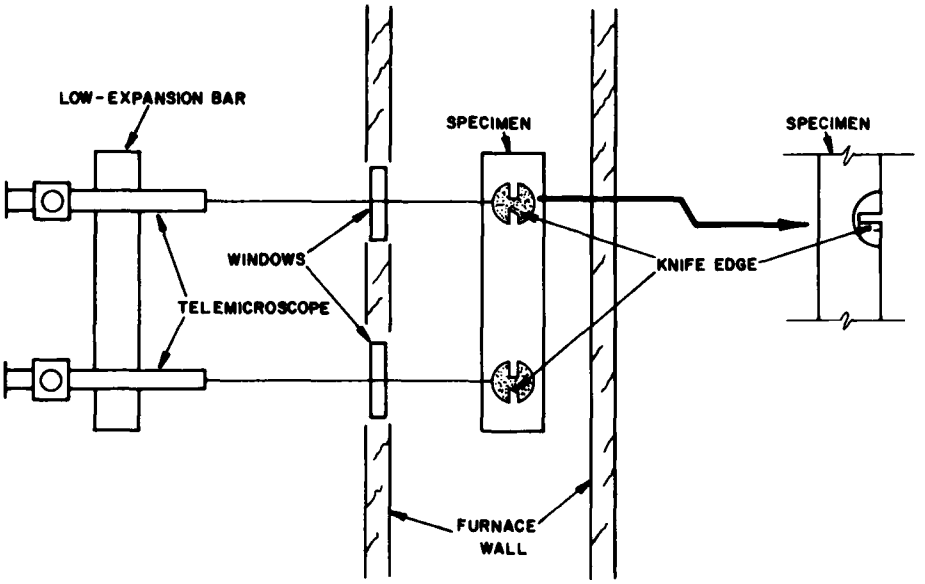


Fig. 14. Schematic diagram for telemicroscope method.

tion of a specimen and a reference material. The general condition for interference is

$$2nL \cos \theta = N\lambda_v \tag{87}$$

where n is the index of refraction of the atmosphere between the surfaces, L the distance between the two surfaces, θ the angle between the direction of the incident rays and the normal to the surfaces, N the order of interference, and λ_v the wavelength of the light in vacuum. Monochromatic light sources that may be used include cadmium, helium, mercury, and sodium low-pressure discharge lamps [55] and a stabilized He–Ne laser [56].

If slightly inclined surfaces are illuminated with collimated light and viewed at normal incidence (θ = 0 for all rays), then fringes of equal inclination are observed. When the surfaces are flat the fringes will be straight; otherwise they are determined by the contour of the surfaces. This type of interference is used in the Fizeau interferometer [57]. If plane-parallel surfaces are illuminated with an extended source (θ will vary), then fringes of equal inclination are observed. This type of interference (concentric rings) is used in the Fabry–Perot interferometer [58].

When an interferometer is used to measure thermal expansion, the expansion of the specimen is given by

$$\frac{\Delta L}{L} = \frac{\lambda_v \, \Delta N}{2nL \cos \theta} - \frac{\Delta n}{n} \tag{88}$$

where ΔN is the number of fringes that pass a fiducial mark and Δn is the change of refractive index. A useful approximation for the refractive index is

$$n = 1 + (n_r - 1)\frac{T_r P}{P_r T} \tag{89}$$

where n_r is the index at the reference temperature T_r and the reference pressure P_r. In vacuum or in a sufficiently low-pressure atmosphere

$$\frac{\Delta L}{L} = \frac{\lambda_v \, \Delta N}{2L \cos \theta} \tag{90}$$

In a Fizeau interferometer (straight fringes) the fractional part of ΔN is easily determined from measurements of the position of the fiducial mark between two fringes. In a Fabry–Perot interferometer (circular fringes) the fractional part, v, is given by

$$v = 1 - p + \frac{nLd_p^2}{f^2 \lambda_v} \tag{91}$$

where d_p is the diameter of the pth fringe (counted from the center of the concentric pattern) and f is the focal length of the lens that forms the pattern. If measurements are made on the second and fourth fringes, the fractional part is

$$v = \frac{3d_2^2 - d_4^2}{d_4^2 - d_2^2} \tag{92}$$

The number of fringes that move past a reference point during the expansion of a specimen can be counted by eye or automatically by photographic [59] or photoelectric [60] techniques. Another way of determining ΔN is by finding the value of N at each temperature. This can be done by using at least three different wavelengths [55]. From Eq. (87) it can be seen that

$$(N_1 + v_1)\lambda_1 = (N_2 + v_2)\lambda_2 = (N_3 + v_3)\lambda_3 \tag{93}$$

where N_1, N_2, and N_3 are the fringe integers and v_1, v_2, and v_3 are the fringe fractions for each of the three wavelengths. In the method of exact fractions a value is guessed for N_1 ($\sim 2nL/\lambda_1$) and using the measured value of v_1 the values of $(N_2 + v_2)$ and $(N_3 + v_3)$ are calculated. This procedure is repeated with different values of N_1 until the calculated values of v_2 and v_3 agree with their measured values. If N is known, then

$$\frac{\Delta L}{L} = \frac{\Delta N}{N} - \frac{\Delta n}{n} \tag{94}$$

The Fizeau interferometer can be used to measure either the absolute or relative expansion of a specimen. In the relative method a pedestal of one material fills most of the space within a ring or cylinder of a second material (see Fig. 15). The pedestal is

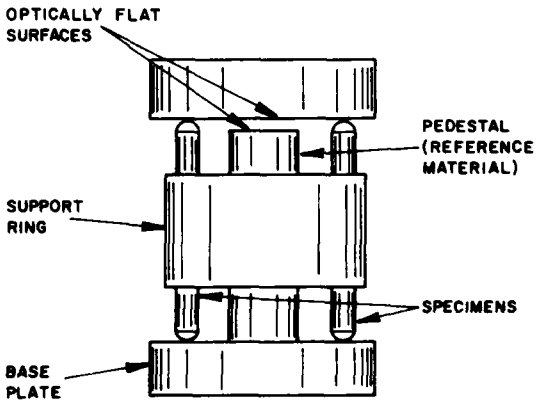


Fig. 15. Schematic diagram for Fizeau interferometer, relative method.

preferably made of a reference material. While the ring supports the optical flat, the interference is formed by reflections from the optical flat and the top surface of the pedestal. Since the reflecting surfaces are close together this method has three advantages: (1) the fringes are bright and well defined; (2) the change of the refractive index of the gas within the small space does not affect the measurements; and (3) longer specimens can be used with a corresponding increase in sensitivity. The thermal expansion is given by

$$\left(\frac{\Delta L}{L}\right)_s = \frac{\lambda_v \Delta N}{2nL_s} + \frac{L_R}{L_s}\left(\frac{\Delta L}{L}\right)_R + \frac{L_s - L_R}{L_s}\frac{\Delta n}{n} \quad (95)$$

where the subscripts refer to the specimen and reference materials. When $L_R \sim L_s$ the last term can be ignored.

If one or all three of the separators in a Fizeau interferometer expand differently, that difference will cause a rotation and/or change in the spacing of the fringes. In the first case where the two similar separators made from a reference material are exactly the same length the difference in expansion of the other material is given by

$$\left(\frac{\Delta L}{L}\right)_s - \left(\frac{\Delta L}{L}\right)_R = \frac{W\lambda_v}{2L_s}\left(\frac{1}{n_2 s_2} - \frac{1}{n_1 s_1}\right) \quad (96)$$

where W is the perpendicular distance between the specimen and the line that joins the separators that are made from the reference material and s is the distance between fringes.

When the optical flats of a Fabry–Perot interferometer are made highly reflecting the multiple reflected beams cause a great increase in sharpness of the fringes. This sharpness results in a higher sensitivity in the measurement of fringe fractions and hence in the expansion measurements. The sensitivity of a polarizing interferometer [61] is also higher because the measurement of the polarization angle is a more sensitive way of determining a fringe fraction. The laser is an extremely efficient source of radiation for this type of interferometer because it can be constructed to emit a polarized beam.

5. X-RAY METHODS

These methods are based on the diffraction of a collimated beam of monochromatic x rays that is scattered by atoms in a crystal lattice. The Bragg law

$$\lambda = 2d(hkl)\sin\theta \quad (97)$$

gives the condition for constructive reflection of the incident radiation. Here d is the separation of the lattice planes, h, k, and l are the Miller indices for the planes, and θ is the angle measured between the direction of the incident or reflected beam and the planes. Except for a small correction due to refraction, the measurement of expansion is independent of wavelength:

$$\frac{\Delta d(hkl)}{d(hkl)} = -\cot\theta\,\Delta\theta = \frac{\sin\theta_1 - \sin\theta_2}{\sin\theta_2} \quad (98)$$

The relationship between the separation of lattice planes and the symmetry of the crystal lattice is given by

$$\begin{aligned} d^2 = {} & [1 - \cos^2\alpha - \cos^2\beta - \cos^2\gamma \\ & + 2\cos\alpha\cos\beta\cos\gamma] \Big/ \left[\left(\frac{h}{a}\right)^2 \sin^2\alpha \right. \\ & + \left(\frac{k}{b}\right)^2 \sin^2\beta + \left(\frac{l}{c}\right)^2 \sin^2\gamma + \frac{2hk}{ab} \\ & \times (\cos\alpha\cos\beta - \cos\gamma) + \frac{2hl}{ac}(\cos\alpha\cos\gamma \\ & \left. - \cos\beta) + \frac{2kl}{bc}(\cos\beta\cos\gamma - \cos\alpha)\right] \end{aligned} \quad (99)$$

Using this equation it can be shown that the expansion of cubic crystals (where $a = b = c$ and $\alpha = \beta = \gamma = 90°$) can be obtained from any set of lattice planes (hkl):

$$\frac{\Delta a}{a} = \frac{\Delta d(hkl)}{d(hkl)} = -\cot\theta\,\Delta\theta \quad (100)$$

For monoclinic crystals, where the symmetry restrictions are $\alpha = \gamma = 90°$, only the expansion in the [0, 1, 0] direction can be obtained directly:

$$\frac{\Delta b}{b} = \frac{\Delta d(0k0)}{d(0k0)} \quad (101)$$

The expansion of the interdependent quantities a, c, and β of a monoclinic crystal can be obtained from the variation of the spacings of three noncoplanar planes of the $(h0l)$ type.

The thermal expansion of crystalline materials can be accurately measured with x-ray cameras and diffractometers under conditions that preclude the use of any other method, as when the specimens are very small, weak, and/or irregular in shape. These methods are also unique in that they can easily be used to determine the principal coefficients of thermal expansion of anisotropic crystals and permit

direct observation of phase changes. There is a further advantage in that measurements with x rays do not include effects that are observed in measurements on bulk specimens.

When using the camera method [62] the specimen must be either a fine-grained polycrystalline wire, a fine powder, or a single crystal that is rotated during the exposure of the film. In powder form the specimen can be held in a thin-walled glass tube. The basic geometry of the Debye–Sherrer method is illustrated in Fig. 16A. The specimen is located at the center of the cylindrical camera and the film is placed on the inside wall. Filtered x rays enter through a collimator and either are diffracted by the crystal planes according to Eq. (97) or are scattered or pass directly through the exit. The diffracted rays are recorded on the film as sharp lines. Figure 16B shows the pattern obtained for a fcc crystal. Not all the angles possible according to Eq. (97) are diffracted, however, because of the structure factor [6]. For example, in the case of a fcc crystal reflections can occur only from those planes for which the Miller indices (hkl) are all even or all odd. The values of θ for the diffracted rays are determined from the position of the lines on the film. For increased accuracy the value of d is obtained using large values of θ. The accuracy also depends upon the centering of the specimen, the axial divergence of the collimated beam, corrections for absorption and refraction within the specimen, knowledge of the camera diameter, and the shrinkage of the film during development.

X-ray diffractometers, in which a diffracted beam is detected with an ionization counter and the angle determined from a wide-angle goniometer, are widely used for expansion measurements [63]. In x-ray diffractometers it must be possible to determine and to adjust the position of the specimen on the focusing circle at any temperature.

The problems associated with heating the specimen and accurately measuring its temperature in both x-ray cameras and diffractometers are discussed in several articles [62–64]. Large temperature gradients across the specimen are often encountered unless special arrangements are made [65]. At 2000 K the temperature gradient may typically be 20 K/cm and the temperature measurements accurate to only 50 K. Even larger values may occur when powder specimens are used. It is possible to use a material of known expansion to determine the temperature [62]. In many cases this reference material can be mixed with the specimen and heated with it.

Unique x-ray techniques exist for special situations. In particular, the use of the Bond technique for single crystals [66] has resulted in a sensitivity of 10^{-7} in measurements of $\Delta a/a$ [67]. In this technique the specimen is rotated between equivalent diffracting orientations on either side of the incident beam. The value of θ thus obtained is unaffected by any specimen eccentricity, absorption, and zero errors, and

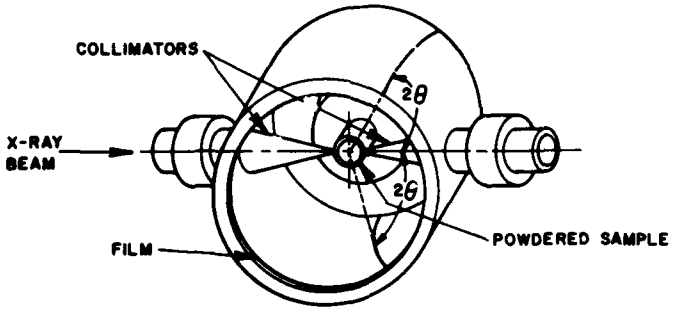


Fig. 16A. Schematic diagram for Debye–Sherrer x-ray camera method.

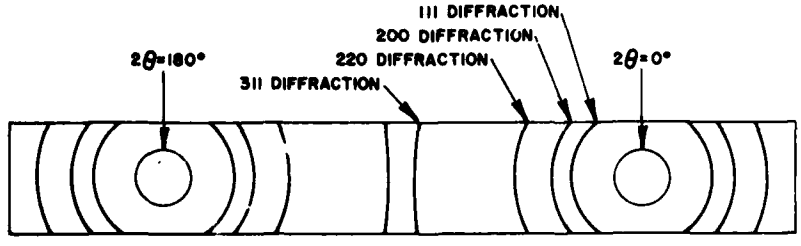


Fig. 16B. Diffraction pattern of face-centered cubic crystal.

errors due to specimen tilt and beam axial divergence are minimized.

Neutron diffraction has also been used to measure thermal expansion [68]. The use of neutrons instead of x rays offers several advantages because the scattering depends upon the nuclei of the atoms instead of the electron distribution. These include the measurement of materials that are composed of light elements such as hydrogen and carbon and of some neighboring elements such as iron and cobalt. Another advantage is that neutrons are diffracted from many deep crystal planes ($\sim 1\ cm^3$) and not from just a few near the surface. This tends to make both furnace construction and temperature measurements easier. Sources of thermal neutrons (atomic reactors) are, however, somewhat more difficult to obtain than sources of x rays.

6. HIGH-SENSITIVITY METHODS

The precise measurement of very small coefficients of linear thermal expansion requires that the sensitivity of the measurements be of the order of 10^{-10}. At low temperatures (<30 K) expansivities are very small (see Table V), but the determination of their temperature dependence contributes a great deal to the understanding of lattice dynamics. On the other hand, the behavior of low-expansion materials at ambient temperatures is of technological importance. Five methods that have been successfully used for these measurements are briefly described.

The three-terminal parallel plate capacitor technique that was developed by White [33] has been used extensively [69–71] in the range of 0 to 310 K. In this technique the capacitance of the plates is measured with a capacitance bridge at about 1000 Hz. The value of the capacitance, C, is about 10 pF and it can be measured with a sensitivity of 10^{-7} pF. As routinely used, this technique measures the relative expansion of the test material,

$$\left(\frac{\Delta L}{L}\right)_s = \left(\frac{\Delta L}{L}\right)_R + \frac{L_R - L_s}{L_s}\left(\frac{\Delta C}{C}\right) \qquad (102)$$

Since $(L_R - L_s)/L_s$ is of the order of 3×10^{-3}, the relative expansion can be measured to 10^{-10}. As can be seen in Fig. 17, the capacitance is measured between electrodes (1) and (2). Electrodes (2) and (3) are both made of the reference material, which is usually copper. Electrode (3) completely surrounds

Table V. Coefficients of Linear Thermal Expansion at Low Temperatures

T, K	Si ($\theta_D \sim 640\ K$)	KCl ($\theta_D \sim 240\ K$)	Al_2O_3 ($\theta_D \sim 1030\ K$)
0	0	0	0
4	3×10^{-11}	1×10^{-9}	2×10^{-11}
8	8×10^{-10}	4×10^{-8}	5×10^{-10}
12	$4+10^{-9}$	3×10^{-7}	3×10^{-9}
16	9×10^{-9}	1×10^{-6}	9×10^{-9}
20	6×10^{-8}	3×10^{-6}	2×10^{-8}
24	-3×10^{-8}		5×10^{-8}
28	-1×10^{-7}		9×10^{-8}
32	-3×10^{-7}		1×10^{-7}
36	-7×10^{-7}		2×10^{-7}
40	-1×10^{-6}		4×10^{-7}

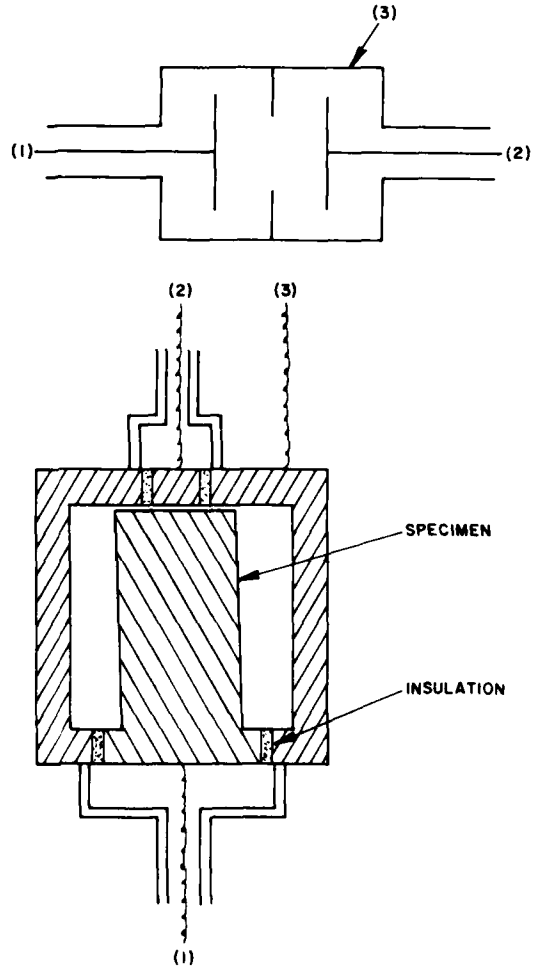


Fig. 17. Schematic diagram for three-terminal parallel plate capacitor technique.

the other two conductors and forms an earth shield so that the capacitance between (1) and (2) does not involve the lead wires.

Kos and Lamarche [72] have used a capacitance technique to measure expansions from 4 to 15 K. In their technique a three-terminal capacitor is connected to a high-Q coil which is immersed in liquid helium to form an LC circuit. The resonant frequency, F, of this circuit is mixed with a standard frequency and the beat frequency is determined with a counter. The expansion of the specimen is given by

$$\left(\frac{\Delta L}{L}\right)_s = \frac{2(L_R - L_s)}{L_s}\left(\frac{\Delta F}{F}\right) \qquad (103)$$

When $\Delta F/F = 2.5 \times 10^{-8}$ and $(L_R - L_s)/L_s = 3 \times 10^{-4}$, the expansion can be measured to 10^{-11}.

A high-sensitivity variable differential transformer was developed by Sparks and Swenson [73] for use from 2 to 40 K. In this technique the relative displacement between the primary and secondary windings of a transformer is detected with a mutual inductance bridge. As the secondary winding moves (see Fig. 18), the change in inductance is balanced by the inductance between the primary and pickup windings. Since the change in mutual inductance is linear to within one percent over ±1 mm and can be measured to 10^{-10}, the expansion can be measured to 10^{-11} when the specimen's length is 10 cm.

While several mechanical–optical systems have been developed [74, 75] the most interesting is that of Pereira, Barnes, and Graham [76] for use from 2 to 30 K. In this system the expansion of a 6-cm specimen causes the rotation of a mirror which is attached to the center of a doubly twisted strip (see Fig. 19). The rotation of the mirror is detected with a photoelectric device that has a sensitivity of $\sim 10^{-8}$ rad. The system is calibrated by the piezoelectric effect of a quartz crystal which is placed in series with the specimen [77]. The response of the quartz crystal is $\sim 2 \times 10^{-10}$ cm/V. The overall sensitivity of the system for measuring expansion is 10^{-11}.

A technique which utilizes the frequency shift of a Fabry–Perot interferometer has been developed by Foster [78] and by Jacobs [34]. The latter has used his system to measure low-expansion materials from 273 to almost 600 K with a sensitivity of 10^{-9}. The beam from a stable He–Ne laser is passed through an electrooptical modulator, an optical isolator, and a Fabry–Perot etalon whose mirrors are separated by a

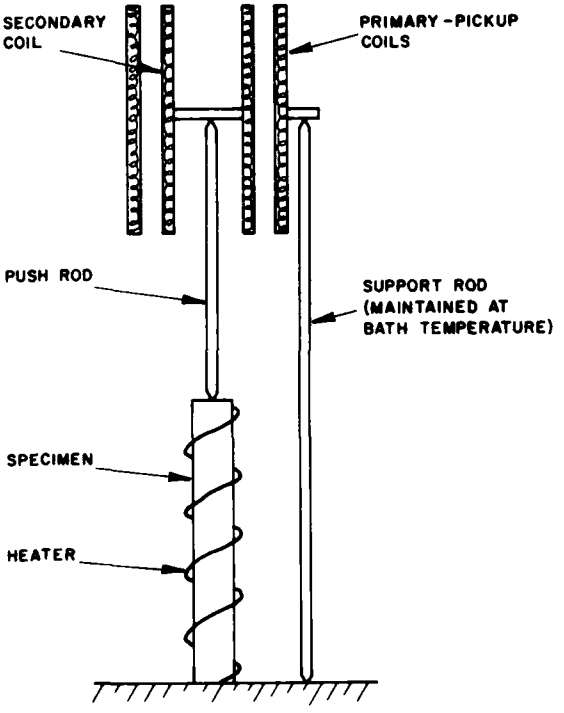


Fig. 18. Schematic diagram for variable differential transformer method.

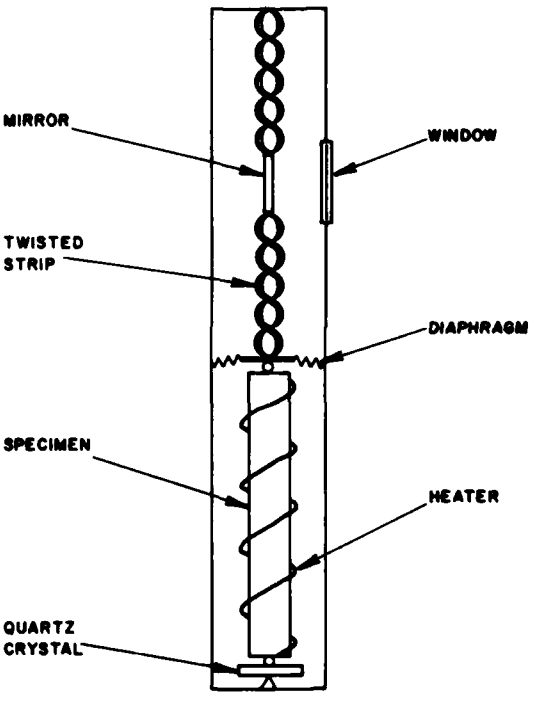


Fig. 19. Schematic diagram for mechanical optical technique.

spacer made from the specimen. The beam is modulated so that frequency sidebands are impressed on it that can be tuned to coincide with a transmission peak of the etalon. At coincidence, light passes through the etalon and the change in modulation frequency is proportional to the expansion of the specimen.

7. HIGH-SPEED METHODS

High-speed methods of measuring various thermophysical properties of electrical conductors have proved to be extremely useful [79]. Although no accurate measurements of thermal expansion have yet been made with these systems, they are feasible and are of future importance. In these systems temperatures above 2000 K can be obtained in less than one second by means of pulse heating in vacuum. Temperatures are measured with high-speed optical pyrometers and the data collected with a digital acquisition system.

Cezairliyan [35] has described a system in which the expansion of a specimen is measured by detecting the change in radiance from a constant radiation source. The change in radiance is caused by the expansion of the specimen which partially blocks the radiation. The incident radiation is modulated at 600 Hz so that an optical pyrometer alternately measures the radiances from the source and specimen alone. The difference between the two radiances is proportional to the width (~ 10 mm) of the specimen.

Ruffino *et al.* [80] have described a very complex system which utilizes two image followers and Michelson interferometer. Each image follower tracks the movement of a hole that has been drilled through the specimen, while a corner cube mounted on the follower forms part of the interferometer which measure the amount of movement.

8. VOLUMETRIC METHODS

Methods of measuring volume thermal expansion are usually applied to organic compounds and polymers that have relatively large coefficients of thermal expansion ($\beta > 50 \cdot 10^{-6}\ \mathrm{K}^{-1}$) and deform under low stresses. Several methods that are used to measure the change in volume of solid materials are briefly described. The use of all but one of these methods depend upon knowing the density as a function of temperature of a liquid (usually mercury, water, or a silicon oil) in which the specimen is immersed. Values for the density of water and mercury that are in excellent agreement with those recommended by the International Union of Pure and Applied Chemistry [81] can be calculated from the following equations:

Water, $273 \le T \le 313$ K

$$\rho(\mathrm{kg\ m^{-3}}) = -17912.96 + 300.6987T - 1.9247037T^2 + 6.200789 \cdot 10^{-3}T^3 - 1.004708 \cdot 10^{-5}T^4 + 6.53633 \cdot 10^{-9}T^5 \quad (104)$$

Mercury, $250 \le T \le 575$ K

$$\rho(\mathrm{kg\ m^{-3}}) = 14305.37 - 2.76072\,T + 6.7171 \cdot 10^{-4}T^2 - 2.4122 \cdot 10^{-7}T^3 - 2.739 \cdot 10^{-10}T^4 + 8.04 \cdot 10^{-14}T^5 \quad (105)$$

The most widely used method is the volume dilatometer [82]. In this method the specimen is placed in a glass bulb to which a long precision capillary tube is connected. After the bulb is sealed it is filled with a liquid by a vacuum technique. The volume of the specimen is determined by hydrostatic weighing and the change in volume of the system is determined by measuring the height of the liquid in the capillary tube at different temperatures. The expansion of the specimen is approximately given by

$$\frac{\Delta V}{V_{293}} = \left(1 + \frac{W_{293}}{V_{293}\rho_{293}} - \frac{AX_{293}}{V_{293}}\right)\beta_G\,\Delta T + \frac{W_{293}}{V_{293}\rho_{293}} - \frac{W_{293}}{V_{293}\rho_T} + \frac{A\,\Delta X}{V_{293}} \quad (106)$$

where W_{293} and ρ_{293} are the weight and density of the liquid at room temperature, ρ_T is the density of the liquid at temperature T, A is the cross-sectional area of the capillary bore, X_{293} is the height of the liquid in the capillary at room temperature, and β_G is the coefficient of thermal expansion of the glass bulb and capillary. For highest precision the ratio of liquid volume to specimen volume and the bore of the capillary tube should be small. For highest accuracy the system should be calibrated with a reference material of known expansion. A picnometer is a variation of the volume dilatometer in which the capillary tube is removed. In this method the change in volume on heating is determined by collecting and weighing the liquid that is expelled from the bulb [83]. A method that was developed within the last 10 years [84] that has the capability for use at much higher temperatures utilizes small glass spheres in

place of a liquid. In this method the system is essentially a tube-type fused-quartz dilatometer with an LVDT extensometer. The specimen is placed in the center of a known volume of glass spheres in the bottom of the tube. The push rod rests on top of the spheres in a piston-type assembly to contain them in the tube. When the system expands, the small glass spheres "flow" around the specimen and lift the push rod in the tube. The expansion of the specimen is given by

$$\frac{\Delta V}{V_{293}} = 2\frac{V_{293}+v_{293}}{V_{293}}\alpha_D\,\Delta T - \frac{v_{293}}{V_{293}}\beta_s\,\Delta T + \frac{A}{V_{293}}\Delta X \tag{107}$$

where v_{293} is the volume of the glass spheres, α_D is the coefficient of linear thermal expansion of the dilatometer, β_s is the coefficient of thermal expansion of the glass spheres, and A is the cross-sectional area of the dilatometer tube.

The volume expansion of a solid can also be determined by the hydrostatic weighing method [85]. In this method the specimen is weighed in a liquid of known density at different temperatures. Corrections must be made for the weight of the wire and the basket or other device that supports the specimen. Corrections must also be made for the effect of surface tension of the liquid on the suspension wire. In this method the expansion is approximately given by

$$\frac{\Delta V}{V_{293}} = \frac{\rho_{293}-\rho_T}{\rho_{293}} - \frac{\Delta W_B}{\rho_{293}V_{293}} + c_0 \tag{108}$$

where ΔW_B is the change in weight of the specimen while suspended in the liquid and c_0 is a correction term. A variation of this method in which the temperature is determined when the liquid and the specimen have equal densities is capable of very high precision. This flotation method as developed by Warrington [86] uses a glass float that can be loaded with both mercury and the specimen in contact with water. In one series of tests the weight of mercury loaded on the float is determined as a function of temperature, $W'_M = f(T)$. In another series of similar tests the specimen is also loaded on the float, $W_M = g(T)$. These functions can be used to calculate W'_M and W_M at the same temperature for use in calculating the expansion of the specimen:

$$\frac{\Delta V}{V_s} = \left(1 - \frac{W'_M - W_M}{\rho_M V_S}\right)_{293}\left(\frac{\Delta\rho_W}{\rho_W}\right) + \left(\frac{W'_M - W_M}{\rho_M V_S}\right)_{293}\left(\frac{\Delta\rho_M}{\rho_M}\right) - \left(\frac{1}{\rho_W V_S} - \frac{1}{\rho_M V_S}\right)_{293}(\Delta W_M - \Delta W'_M) \tag{109}$$

where ρ_M and ρ_W are the densities of mercury and water.

Other Major Sources of Thermal Expansion Data

There exists in the literature a number of reference sources which, while less extensive in scope than the present volume, may nevertheless prove valuable to the reader. While it is not the intent to cite here every available review, it is felt that the following works may prove to be of some value.

Volumes I and II of the *International Critical Tables* [87] contain thermal expansion data on a variety of materials, but these data are rather out of date. Similarly, the *Smithsonian Physical Tables* [88] give data on a variety of materials. Corruccini and Gniewick [89] give data on technical solids at cryogenic temperatures. A summary report on ceramics by Stutzmann, Salvaggi, and Kirchner gives data on ceramics [90]. Wood and Deem [91] include thermal expansion data in their compilation of thermophysical property data for materials useful above 1500 K. Properties of selected ceramic materials are given in a compilation edited by Lynch, Ruderer, and Duckworth [92]. Pearson [93] gives a summary of published lattice thermal expansion data.

Touloukian [94] edited a handbook series of six volumes (nine books) entitled *Thermophysical Properties of High Temperature Solid Materials*. Volumes 5 and 6 include data on oxides, carbides, polymers, composites, etc. This series is an update of the five-volume series of Goldsmith, Waterman, and Hirschhorn [95] entitled *Handbook of Thermophysical Properties of Solid Materials*, which includes data on thermal expansion for materials melting above 1000°F. Data on a variety of materials are also included in the Landolt–Börnstein tables [96]. A recent handbook containing evaluated thermal expansion data is the *American Institute of Physics Handbook*, Third Edition (1972) [97], but these evaluations have been taken into account in the present Volumes 12 and 13.

Comprehensive bibliographic citations (not data) are included in Volumes 1 and 3 of the six-volume *Supplement I* to *Thermophysical Properties Research Literature Retrieval Guide*, edited by Touloukian, Gerritsen, and Shafer [98].

In addition to the above works, the proceedings of the *Thermal Expansion Symposia* [99, 100, 101] represent valuable references to data, methods, and theory on thermal expansion.

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Numerical Data

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Data Presentation and Related General Information

1. SCOPE OF COVERAGE

This volume presents the data on the percent thermal linear expansion and coefficient of thermal linear expansion for almost all the important kinds of nonmetallic solid materials for which experimental data are available. The materials covered include 11 elements, 23 groups of graphites, 61 simple oxides, 76 complex oxides, 48 salts, 127 nonoxide compounds, 5 groups of ceramics, 11 groups of cermets, 15 groups of glasses, 60 polymers, and 15 groups of composites. These data were obtained by processing over 2300 research documents dated from 1908 to 1974 including a number of articles published more recently. Materials within each category are arranged alphabetically by name, as listed in the *Grouping of Materials and List of Figures and Tables* in the front of the volume. In all, this volume reports 4990 sets of experimental data on 815 different materials, which are listed in the *Material Index* at the end of the volume.

Of the 452 materials and groups of materials covered, the data for 228 (i.e., 50.4%) have been critically evaluated, analyzed, and synthesized, and recommended reference values or provisional values have been generated and are presented in this volume together with the original experimental data.

The temperature ranges covered by the thermal expansion data for many materials are from near absolute zero to near the melting point. The change in the thermal expansion due to transitions such as phase transition and glass transition are also taken into account.

It is important to note that, although the numerical data presented in this volume are all for thermal *linear* expansion, values for thermal *volumetric* expansion can easily be calculated from the data for thermal *linear* expansion by using the equations given in the text on the theory of thermal expansion. Consequently, this volume is useful for both *linear* and *volumetric* thermal expansion of nonmetallic solids.

2. PRESENTATION OF DATA

The thermal expansion data and information for each material are presented generally in four sections arranged in the following order: (1) Recommended Table and Figure, (2) Original Data Plot, (3) Specification Table, and (4) Data Table.

Recommended values for the percent thermal linear expansion of materials for which critical data evaluation and analysis are possible are presented in both tabular and graphical forms. In addition, a table of the coefficient of thermal linear expansion is also given. An empirical equation in the form of a cubic polynomial is given in the REMARKS to the table to approximately represent the recommended percent expansion values. A brief discussion of the basis used in arriving at the recommended percent expansion values and at the values for the cofficient of expansion and a statement of the uncertainties in these values are also given in the REMARKS.

The Original Data Plot is a full-page linear-scale graphical presentation of the thermal linear expansion data as a function of temperature. The data on the coefficient of thermal linear expansion for temperatures below 293 K are given in an insert. Although the recommendation made is for a pure material, this type of figure should give an excellent overall view of the quality of data available from the literature. For a number of materials for which there exists only a small number of data, the Original Data Plot is omitted. When several sets of data are too close together to be distinguishable, some of the curves (or data sets) are omitted from the plot for the sake of clarity. These are clearly indicated by asterisks in both the Specification Table and the Data Table.

The Specification Table provides in a concise form the comprehensive information on the test specimens for which data are reported. The curve numbers in the Specification Table correspond exactly to the numbers which appear in the Original Data Plot and the Data Table. The Specification

Table gives for each set of data the reference number which corresponds to the number in the list of References to Data Sources, the names of authors, the year of publication of the document, the method of measurement, the temperature range, the particular name of the material other than that appearing in the title of the table, the specimen designation, and the specimen composition, characterization, and the test conditions, which include any variables reported by the investigator that may be responsible for the variation in the thermal expansion data. The information of the last category, which is reported to the extent provided in the original source document, includes the following:

1. Purity, chemical composition, and concentration of crystal defects.
2. Type of crystal and crystal axis orientation
3. Microstructure, grain size, inhomogeneity, and additional phases
4. Specimen shape and dimensions, and method and procedure of fabrication
5. Thermal history, heat treatment, and mechanical, irradiative and other treatments
6. Manufacturer and supplier, stock number, and catalog number
7. Test environment, degree of vacuum or pressure, strength and orientation of applied magnetic field
8. Pertinent physical properties such as density, porosity, hardness, and transition temperature
9. Form in which the extracted data are presented in the original source document other than raw data points
10. Additional information obtained directly from the author

Unfortunately, in the majority of cases the authors do not report in their research papers all the necessary pertinent information to adequately characterize and identify the materials for which their data are reported. This is particularly true for the authors of earlier investigations. Consequently, the amount of information on specimen characterization reported in the Specification Tables varies greatly from author to author.

Tabular presentation for all the data described in the Specification Table whether shown or not in the Original Data Plot is given in the Data Table. Attempts have been made to contact authors for tabular data whenever the original data are given in the research paper in a graph which is too small to allow accurate data extraction compatible with the accuracy of the measurements.

Data on percent thermal linear expansion are reported in this volume as percent elongation, given by the expression

$$\frac{\Delta L}{L_0}(\%) = \frac{L_T - L_{293\,K}}{L_{293\,K}} \times 100$$

where L_T and L_0 are lengths (or lattice parameters) at temperature T and at 293 K, respectively. In order to compare all the available data from the world literature on the same basis, the thermal expansion has been arbitrarily set to be zero at 293 K, whenever this is possible. In these cases the zero-point correction or the lattice parameters at the first measured temperature and the extrapolated value at 293 K are given in the Specification Table. This information is useful in deriving the original data from the presented data. In the cases where it is not feasible to convert the author's original data to a 293 K reference (because of a large extrapolation required or of problems associated with phase transformations), the presented form differs from this, and the new reference temperature is specified in the Specification Table. In the cases where data were taken during the subsequent cooling or heating cycles in the measurement and "permanent sets" have occurred, the data have been biased to zero expansion at 293 K and the appropriate zero-point corrections are indicated in the Specification Tables. These curves are not shown in the Original Data Plot and this fact is indicated clearly on the individual curves by asterisks in the Specification and Data Tables. Whenever an author reports data on both thermal linear expansion and the coefficient of thermal expansion, the latter is also reported in a second Data Table. In this case the same curve number is used in the Original Data Plot, Specification Table, and the two Data Tables. In this way, the information in the Specification Table for a given specimen applied to data on both the thermal linear expansion and the coefficient of thermal linear expansion for that specimen. If the author only reported coefficient of expansion data, these results are integrated to yield values of thermal expansion and this is indicated by a double dagger (‡) in the Data Table.

The coefficient of thermal linear expansion is defined as

$$\alpha = \frac{d}{dT}\left(\frac{\Delta L}{L_0}\right) = \frac{1}{L_0}\frac{dL}{dT}$$

As discussed in the text on the theory of thermal expansion of solids, there are several other commonly used definitions of the coefficient; most frequently used is the mean coefficient between two temperatures. Since the mean coefficient is applied to a range of temperature and cannot be specified for a single temperature, such data are not reported. Instead, they have been converted to thermal linear expansion.

3. CRITERIA FOR DATA ANALYSIS

The end result of critical evaluation, analysis, and synthesis of the available data is the generation of the "most probable values." Depending upon the level of confidence these values are designated as "recommended values" or "provisional values." Whenever possible, the reliability of experimental data is judged on the basis of a set of objective criteria. However, there are many instances where adequate information is not provided by the author that can be used for the full assessment of the quality of the data. In such cases, data evaluation becomes exceedingly difficult, and considerable weight is given to factors such as past performance of the author and the reputation of the laboratory where the measurement was made. In general, the recommended values are derived from the experimental data that consist of concordant results from measurements carried out by several reliable and competent researchers on well-characterized materials using proven techniques, or of the results of a single reliable and competent researcher on well-characterized materials using at least two independent methods. Any serious deviation from these conditions may lead to the designation of the derived values as "provisional values." The uncertainty in the recommended percent expansion values is $\leq \pm 5\%$ and the uncertainty in the provisional percent expansion values is $> \pm 5\%$.

The values for the coefficient of thermal linear expansion are obtained from critical evaluation of the experimental data whenever available. These values are compared with the calculated values obtained by differentiating the cubic polynomial equation given in the REMARKS to the table or the more elaborate cubic spline fit equations that fit the recommended percent thermal linear expansion values. This procedure is followed to ensure the consistency between the values of the percent thermal expansion and those of the coefficient of thermal expansion. Whenever experimental data for the thermal expansion coefficient are not available, the values are obtained by differentiation of the equations mentioned above, with the resulting values (particularly the end points) slightly adjusted, if necessary, in order to be consistent with the general shape of the thermal expansion curve.

4. CLASSIFICATION OF MATERIALS

The classification of most of the materials covered in this volume is based on the chemical composition of the material using the classification scheme shown in Table VI. This scheme is mainly for the convenience of materials grouping and data organization and is not intended to be used as the

Table VI. Classification of Nonmetallic Materials

Classification		Limits of composition weight percent)*			
		X_1	X_1+X_2	X_2	X_3
1. Elements		>99.5	—	<0.2	<0.2
2. Mixtures (or solutions) of elements or of elements and compounds	A. Binary	—	≥99.5	≥0.2	≤0.2
	B. Multiple	—	≥99.5	>0.2	>0.2
		—	<99.5	≥0.2	≤0.2
		—	<99.5	>0.2	>0.2
		≤99.5	—	<0.2	<0.2
3. Compounds		>95.0	—	<2.0	<2.0
4. Mixtures (or solutions) of compounds	A. Binary	—	≥95.0	≥2.0	≤2.0
	B. Multiple	—	≥95.0	>2.0	>2.0
		—	<95.0	≥2.0	≤2.0
		—	<95.0	>2.0	>2.0
		≤95.0	—	<2.0	<2.0

* $X_1 \geq X_2 \geq X_3 \geq X_4 \geq \cdots$.

basic definitions for the various material categories. Because of their inherent nature, certain materials do not lend themselves to a purely chemical classification and a more logical method has been adopted to classify them, instead, by their physical form and/or use and application.

The oxygen-containing inorganic compounds of compositions A_mO_z and $A_mB_nO_z$, in which A and B represent elements, are classified into the following three groups. Any compound containing one element plus oxygen such as A_mO_z, where A can be metallic or nonmetallic element, is classified as *Simple Oxide*, e.g., Al_2O_3, ZrO_2, etc. For compounds of composition $A_mB_nO_z$, the following scheme is adopted for their classification. If both A and B are metallic elements and B is less metallic and more strongly electronegative so that the B–O binding can no longer be treated as primarily ionic, then this compound is considered to be a *Complex Oxide* with the formula $A_mO_y \cdot B_nO_{z-y}$ and named as AB oxide, e.g., $CaO \cdot Al_2O_3$, $SrO \cdot ZrO_2$, etc. These complex oxides are arranged in the alphabetical order by name of the B elements. If the central element B is nonmetallic, the compound is considered to be a *Salt* of the common inorganic acid of B element is named by the appropriate anion name, with its chemical formula in the usual form for salt, e.g., $CaCO_3$, Mg_2SiO_4, etc. Materials known as ceramics, especially those specified by the trade names, are placed in the category of *Ceramics*. If a material meets the criteria of a cermet or, in some cases, is designated as "cermet" by the author of the original paper, it is placed in the category of *Cermets* and is listed in alphabetical order by the primary nonmetallic component. Thus, the two cermets 60% Al_2O_3 + 30% Cr + 10% Cr_2O_3 and 60% Cr + 30% Al_2O_3 + 10% Cr_2O_3 are both listed under $Al_2O_3 + Cr + \Sigma X_i$ cermet. Oxygen-containing materials known to be in the glassy state are placed in the category of *Glasses*. The materials are arranged according to the composition within this category.

5. SYMBOLS AND ABBREVIATIONS USED IN THE TABLES AND FIGURES

In the specification tables the code designations used for the experimental methods are as follows:

D	Density method
E	Electrical capacitor method
F	Electron diffraction
I	Interferometer method
L	Dilatometer method
O	Optical method
R	Variable resistance transducer
S	Strain gauge method
T	Telemicroscope method
V	Variable inductance transformer
X	X-ray diffraction method

Other symbols and abbreviations used in the tables and/or figures are as follows:

b.c.c.	Body-centered cubic
c.	Cubic
c.p.h.	Close-packed hexagonal
d	Density
f.c.c.	Face-centered cubic
f.c.t.	Face-centered tetragonal
h.	Hexagonal
I.D.	Inside diameter
$\Delta L/L_0$	Percent thermal linear expansion
α	Coefficient of thermal expansion
M.P.	Melting point
monocl.	Monoclinic
NTP	Normal temperature and pressure
O.D.	Outside diameter
orthorh.	Orthorhombic
r.	Rhombohedral
s.c.	Superconducting
Subl.	Sublimation
T	Temperature
t.	Tetragonal
Temp.	Temperature
T.P.	Transition point
trig.	Trigonal
μ	Micro
>	Greater than
<	Less than
~	Approximately
③	Curve number for polycrystalline material if any of the following three kinds of curve number symbols appears also in the same figure; otherwise it just represents any curve number
⟨3⟩	Curve number for measurements//to *a*-axis unless otherwise indicated
◇3◇	Curve number for measurements//to *b*-axis
[3]	Curve number for measurements//to *c*-axis unless otherwise indicated

6. CONVENTION FOR BIBLIOGRAPHIC CITATION

For the following types of documents the bibliographic information is cited in the sequences given below.

Journal Article

a. Author(s)—The names and initials of all authors are given. The last name is written first, followed by initials.
b. Title of article.
c. Journal name—The abbreviated name of the journal as used in the *Chemical Abstracts* is given.
d. Series, volume, and number—If the series is designated by a letter, no comma is used between the letter for series and the numeral for volume, and they are underlined together. If the series is also designated by a numeral, a comma is used between the numeral for series and the numeral for volume, and only the numeral representing volume is underlined. No comma is used between the numerals representing volume and number. The numeral for number is enclosed in parentheses.
e. Pages—The inclusive page numbers of the article are given.
f. Year—The year of publication.

Report

a. Author(s).
b. Title of report.
c. Name of the responsible organization.
d. Report or bulletin, circular, technical note, etc.
e. Number.
f. Part.
g. Pages.
h. Year.
i. ASTIA's AD number—That is given in square brackets whenever available.

Book

a. Author(s).
b. Title.
c. Volume.
d. Edition.
e. Publisher.
f. City, state (address of the publisher).
g. Pages.
h. Year.

7. CONVERSION FACTORS

The following conversion factors are used for the conversion of the data/values reported in the Specification Tables and Data Tables:

$$1 \text{ in.} = 0.0254 \text{ m}$$

$$1 \text{ lb} = 0.45359237 \text{ kg}$$

$$1 \text{ kX} = 1.00202 \text{ Å}$$

$$T(\text{K}) = t(^\circ\text{C}) + 273.15$$

$$T(\text{K}) = [5/9][t(^\circ\text{F}) + 459.67]$$

The same number of decimal places as in the original data given by the author was retained in the temperature conversion.

The kilo X unit (kX) was used in early years for relative wavelength measurements and is defined by the relation

$$1 \text{ kX} = \frac{(200) \text{ plane spacing of calcite}}{3.02945}$$

8. CRYSTAL STRUCTURES, TRANSITION TEMPERATURES, AND PERTINENT PHYSICAL CONSTANTS OF THE ELEMENTS, AND CRYSTAL STRUCTURES, DENSITIES, AND MELTING POINTS OF SELECTED INORGANIC COMPOUNDS

Table VII contains information on the crystal structures, transition temperatures, and certain pertinent physical constants of the elements. Crystal structures, densities, and melting points (wherever available) of the inorganic compounds covered in this volume for which information is available are given in Table VIII. This information is very useful in data analysis and synthesis. For example, the thermal expansion of a material generally changes abruptly when the material undergoes any transformation. One must therefore be extremely cautious in attempting to extrapolate the thermal expansion data across any phase, state, or magnetic transition temperature, as given in the table. Each table has an independent series of numbered references which immediately follows the table.

Even though no attempt has been made to critically evaluate the temperatures/constants given in the tables and these should not be taken as recommended reference values, Table VII for the elements is significantly different from the similar table published earlier in Volumes 1, 2, 4, 5, 7, and 10 of this Series. This revised Table VII is an updated and upgraded version of the earlier table in that most of the information/data given in Table VII have been taken from more recent and reliable sources and that all temperatures have been converted to the International Practical Temperature Scale of 1968 (IPTS-68).

In Table VIII for the inorganic compounds, the melting points are given in both IPTS-48 and IPTS-68 with the latter in parentheses. It should be noted that some materials do not melt but decompose or sublime at high enough temperature, and that for these materials the temperatures given in the melting point column are decomposition or sublimation temperatures rather than melting points, which have been so noted in the table.

Table VII. Crystal Structures, Transition Temperatures, and Pertinent Physical Constants of the Elements[a]

Name	Atomic Number	Atomic[b] Weight	Density[c], kg m^{-3} x 10^{-3}	Crystal Structure	Phase Transition Temp., K	Superconducting Transition Temp., K	Curie Temp., K	Néel Temp., K	Debye Temperature		Melting Point, K	Boiling Point, K	Critical Temp., K
									At 0 K, K	At 298 K, K			
Actinium	89	(227)	10.07[d]	f.c.c.[10]					124[3]	100[4] (at ~50 K)	1324[16]	~~3200~~ 3473 ± 300[6]	
Aluminum	13	26.9815[4]	2.702[16]	f.c.c.[10]		1.196[16] 1.17[9] 1.183[16]			423 ± 5[3]	390[3]	933.52[37]	2798[21]	8680[11] 7795[49]
Americium	95	(243)	11.7[12]	Double c.p.h.[10]							1269 ± 4[21]	2885[75]	
Antimony	51	121.75	6.684[20]	r.[10]					150[3]	200[14]	903.89[37]	1860 ± 50[21]	2994[15]
Argon	18	39.948	0.0017824[28] (at 273.2 K and 1 atm)	f.c.c.[9]						90[4] (at ~45 K)	83.81[21]	87.30[21]	151[15]
Arsenic	33	74.9216	5.73[10] (gray, at 295.7 K) 4.7[29] (black) 2.0[29] (yellow)	r.[10] (gray) orthorh.[10] (black) c.[5] (yellow)					236[3]	275[18]	1091[13] (35.8 atm) subl. 886[16]	1091[13] (35.8 atm)	
Astatine	85	(210)									573.2[19]	650[20]	
Barium	56	137.34	3.5[16]	b.c.c.[10] (α)					110.5 ± 1.8[22]	116[21]	1002 ± 2[21]	2174[21]	3670[15] 3928[49]
Berkelium	97	(249)											
Beryllium	4	9.01218	1.85[16]	c.p.h.[10] (α) b.c.c.[10] (β)	1530[10] (α-β)				1160[25]	1031[3]	1562[21]	2749[21]	6170[15]
Bismuth	83	208.9804	9.78[16]	r.[10]					119 ± 2[3]	116 ± 5[3]	544.592[37]	1839[21]	4620[27]
Boron	5	10.81	2.50[42]	Simple r.[10] (α)					1315[53]	1362[3]	2573[16]	4284[21]	
Bromine	35	79.904	3.119[29]	orthorh.[9]							265.9[21]	332.25[21]	584[15]
Cadmium	48	112.40	8.65[16]	c.p.h.[10]		0.56[16] 0.518[21]			252 ± 48[3]	221[3]	594.258[37]	1038[3]	1905[15] 3567[49]
Calcium	20	40.08	1.55[16]	f.c.c.[10] (α) b.c.c.[10] (β)	720 ± 2[21] (α-β)				234 ± 5[3]	230[3]	1113 ± 2[21]	1759[21]	3273[15]
Californium	98	(251)											
Carbon (amorphous)	6	12.011	1.8 ~ 2.1[28]								Subl. 3925-3970[5]	4473[5]	
Carbon (diamond)	6	12.011	3.52[16]	d.[9]					2240 ± 5[31]	1874[3]	>3823[16]	5100[16]	
Carbon (graphite)	6	12.011	2.25[16] (α)	h.[9] (α) r.[9] (β)					402 ± 11[3]	1550[3]	Subl. 3925-3970	4484[5]	

[a] All temperatures have been converted to the International Practical Temperature Scale of 1968 (IPTS-68).

[b] Atomic weights are based on $^{12}C = 12$ as adopted by the International Union of Pure and Applied Chemistry in 1971; those in parentheses are the *mass numbers* of the isotopes of longest known half-life.

[c] Density values are given at 293.2 K unless otherwise noted.

[d] *Superscript* numbers designate references listed at the end of the table.

Name	Atomic Number	Atomic Weight[b]	Density[c], kg m^{-3} x 10^{-3}	Crystal Structure	Phase Transition Temp., K	Superconducting Transition Temp., K	Curie Temp., K	Néel Temp., K	Debye Temperature		Melting Point, K	Boiling Point, K	Critical Temp., K
									At 0 K, K	At 298 K, K			
Cerium	58	140.12	6.90 [20]	f.c.c. [10] (α) Double c.p.h. [10] (β) f.c.c. [10] (γ) b.c.c. [10] (δ)	103 ± 5 [33] (α-β) 263 ± 5 [9] (β-γ) 1003 (γ-δ)			13 [32]	146 [3]	138 [34]	1072 ± 3 [21]	3699 [16]	10440 [49]
Cesium	55	132.9054	1.873 [20]	b.c.c. [10]					40 ± 5 [3]	43 [23]	301.55 [21]	944 [16]	2063 [46, 47, 48] 1900 [49]
Chlorine	17	35.453	0.003214 [20] (at 273.2 K)	t. [9]						115 [4, 36] (at ~58 K)	172.16 [21]	239.10 [21]	417 [15]
Chromium	24	51.996	7.14 [16]	b.c.c. [21]				311 [37]	598 ± 32 [3]	424 [3]	2133 ± 20 [21]	2950 [21]	
Cobalt	27	58.9332	8.862 [42]	c.p.h. [10] (α) f.c.c. [10] (β)	690 [73] (α-β)		1395 [74] (α) 1131 [74] (β)		452 ± 17 [3]	386 [3]	1767 [37]	3207 [21]	
Copper	29	63.546	8.933 [16]	f.c.c. [10]					342 ± 2 [3]	310 [3]	1357.6 [37]	2840 [21]	8530 [11] 8310 [49]
Curium	96	(247)	7 [42]	Double c.p.h. [8]									
Dysprosium	66	162.50	8.556 [42]	c.p.h. [10] (α) b.c.c. [10] (β)	1659 [21] (α-β)		83.5 [43] (ferro.-antiferromag.)	174 [43]	172 ± 35 [3]	158 [44]	1684 [21]	2835 [16]	7665 [49]
Einsteinium	99	(254)											
Erbium	68	167.26	9.06 [42]	c.p.h. [10] (α) b.c.c. [10] (β)			19 [4] (ferro.-antiferromag.)	80 [4]	134 ± 10 [45]	163 [44]	1797 [12]	3136 [16]	7274 [49]
Europium	63	151.96	5.245 [28]	b.c.c. [10]				~90 [4] 88 [76]	127 [3]		1091 [21]	1870 [16]	4611 [49]
Fermium	100	(253)											
Fluorine	9	18.99840	0.001695 [20] (at 273.2 K and 1 atm)	c. [15] (β-F_2)							53.48 [21]	84.95 [21]	144 [15]
Francium	87	(223)							39 [3]		300.2 [19]	879 [75]	
Gadolinium	64	157.25	7.87 [42]	c.p.h. [10] (α) b.c.c. [10] (β)	1535 [32] (α-β)		291.8 [1]		170 [3]	155 ± 3 [3]	1587 ± 2 [12]	3539 [16]	8700 [49]
Gallium	31	69.72	5.91 [20]	orthorh. [4] (α) t. [4] (β)		1.091 [16] ~~1.083~~ 1.078 [21]			317 [3]	240 ~~[3]~~ [4] 125 [4] (tetra at ~63 K)	302.90 [21] 275.6 [13] (at 8.86 x 10^6 mm Hg)	2482 [21]	7645 [27]
Germanium	32	72.59	5.36 [20]	d. [10]					378 ± 22 [3]	403 [3]	1211.7 [21]	3112 [21]	5656 [15]
Gold	79	196.9665	18.88 [16]	f.c.c. [10]					165 ± 1 [7]	178 ± 8 [3]	1337.58 [37]	3135 [21]	9540 [11] 8090 [49]
Hafnium	72	178.49	13.3 [16]	c.p.h. [10] (α) b.c.c. [10] (β)	2015 ± 20 [21] (α-β)				256 ± 5 [3]	213 [23]	2500 ± 20 [21]	4891 [21]	

Name	Atomic Number	Atomic Weight[b]	Density[c], kg m^{-3} x 10^{-3}	Crystal Structure	Phase Transition Temp., K	Superconducting Transition Temp., K	Curie Temp., K	Néel Temp., K	Debye Temperature		Melting Point, K	Boiling Point, K	Critical Temp., K
									At 0 K, K	At 298 K, K			
Helium	2	4.00260	0.0001785 [29] (at 273.2 K and 1 atm)	c.p.h. [16]						30 [4] (at ~15 K)	3.45 [29] 1.8 ± 0.2 [17] (at 30 atm)	~~4.216~~ [21] 4.215	5.3 [15]
Holmium	67	164.9304	8.80 [29]	c.p.h. [10] (α) b.c.c. [10] (β)	1703 [12] (α-β)		17.5 [72] (ferro.-antiferromag.)	133 ± 2 [72]	114 ± 7 [45]	161 [44]	1745 [12]	2968 [16]	
Hydrogen	1	1.0079	0.00008987 [29] (at 273.2 K and 1 atm)	c.p.h. [9]						116 [36] (para., at ~58 K) 105 [36] (ortho., at ~53 K)	13.803 [21]	20.397 [37]	33.3 [15]
Indium	49	114.82	7.3 [29]	b.c.t. [10]		3.4035 [16] 3.407 ~~21~~			108.8 ± 0.3 [3]	129 [14]	429.784 [37]	2349 [21]	4380 [15] 7070 [49]
Iodine	53	126.9045	4.94 [16]	orthorh. [9]						105 [4] (at ~53 K)	386.7 [21] subl. 298.16 [13] (at 0.31 mm Hg)	458.4 [21]	785 [15] 819 [24]
Iridium	77	192.22	22.5 [42]	f.c.c. [10]		0.105 ± 0.004 [21]			425 ± 5 [3]	228 [3]	2720 [37]	4712 [21]	
Iron	26	55.847	7.87 [28]	b.c.c.-ferromag. [10] (α) b.c.c.-paramag. [10] (β) f.c.c. [10] ~~(γ)~~ (γ) b.c.c. [10] (δ)	1185 [21] (β-γ) 1667 [21] (γ-δ)		1043 ~~21~~		457 ± 12 [3]	373 [3]	1811 [21]	3140 [21]	6770 [30] 9440 [49]
Krypton	36	83.80	0.003708 [29] (at 273.2 K and 1 atm)	f.c.c. [16]						60 [4] (at ~30 K)	115.78 [21]	119.80 [21]	209.4 [15]
Lanthanum	57	138.9055	6.18 [42]	Double c.p.h. [10] (α) f.c.c. [10] (β) b.c.c. [10] (γ)	583 [32] (α-β) 1141 [32] (β-γ)	~~4.90~~ ~~4.87~~ 4.87±0.02 [21] (α) ~~4.90~~ ~~6.00~~ 6.00±0.02 [21] (β) ~~6.00~~ (γ)			142 ± 3 [52]	135 ± 5 [44]	1195 ± 5 [21]	3730 [16]	10550 [49]
Lawrencium	103	(257)											
Lead	82	207.2	11.342 [16]	f.c.c. [10]		7.193 [5]			102 ± 5 [3]	87 ± 1 [3]	600.652 [37]	2026 [21]	5415 [27] 4770 [49]
Lithium	3	6.94	0.534 [16]	c.p.h. [10] (α) b.c.c. [10] (β)	80 ± 10 [21] (α-β)				352 ± 17 [3]	448 [3]	453.7 [21]	1617 [21]	4160 [11] 3727 [49]
Lutetium	71	174.97	9.85 [29]	c.p.h. [10] (α) b.c.c. [10] (β)	Near m.p. [50] (α-β)				210 [54]	116 [3]	1938 [21]	3668 [16]	
Magnesium	12	24.305	1.74 [16]	c.p.h. [10]					396 ± 54 [3]	330 [3]	922 [21]	1364 [21]	3537 [49]
Manganese	25	54.9380	7.43(α) [28] 7.29(β) [28] 7.18(γ) [28]	b.c.c. [10] (α) c. [10] (β) f.c.c. [10] (γ) b.c.c. [10] (δ)	980 ± 20 [21] (α-β) 1360 ± 20 [21] (β-γ) 1411 ± 20 [21] (γ-δ)			95 (α) ~580 [15] (β) 660 [74] (γ)	418 ± 32 [3]	363 [3]	1519 ± 5 [21]	2338 [21]	6067 [49]
Mendelevium	101	(256)											

Name	Atomic Number	Atomic Weight[b]	Density[c], kg m^{-3} x 10^{-3}	Crystal Structure	Phase Transition Temp., K	Superconducting Transition Temp., K	Curie Temp., K	Néel Temp., K	Debye Temperature		Melting Point, K	Boiling Point, K	Critical Temp., K
									At 0 K, K	At 298 K, K			
Mercury	80	200.59	13.546[29] 14.19[29] (at 234.25 K)	r.[10] (α) b.c.t.-pressure induced structure (β)	Martensitic[56] transformation at low temp.	4.16[16] (α) 4.154[16] (α) 3.949[16] (β)			~75[58]	92 ± 8[3]	234.288[37]	629.81[37]	1735[27] 1707[49]
Molybdenum	42	95.94	10.24[42]	b.c.c.[10]		0.92[16] 0.917[16]			459 ± 11[3]	377[3]	2894 ± 10[35]	4924[21]	17100[11] 16900[49]
Neodymium	60	144.24	7.007[29]	Double c.p.h.[10] (α) b.c.c.[10] (β)	1129[21] (α-β)			8[4] (ordinary) 19[4] (special)	159[3]	148 ± 8[3]	1290 ± 5[21]	3341[21]	7930[49]
Neon	10	20.179	0.0009002[29] (at 273.2 K and 1 atm)	f.c.c.[9]						60[4] (at ~30 K)	24.553[21]	27.102[37]	44.5[15]
Neptunium	93	237.0482	20.46[42]	orthorh.[10] (α) t.[10] (β) b.c.c.[10] (γ)	551[2] (α-β) 847 ± 5[26] (β-γ)				121[3]	163[3]	910 ± 2[21]	4160[3]	
Nickel	28	58.71	8.90[42]	f.c.c.[10]			631[40]		427 ± 14[3]	345[3]	1728[37]	3193[21]	6312[15] 11800[49]
Niobium	41	92.9064	8.57[42]	b.c.c.[10]		9.26[16] 9.17[16] 9.1[8]			241 ± 13[3]	260[64]	2744[21]	5029[21]	19200[49]
Nitrogen	7	14.0067	0.0012506[29]	c.[9] (α) h.[17] (β)	35.61[21] (α-β)					70[4] (at ~35 K)	63.14[21]	77.348[37]	126.2[15]
Nobelium	102	(254)											
Osmium	76	190.2	22.48[29]	c.p.h.[10]		0.655[16] 0.65[8]			500[67]	400[68]	3288 ± 10[69]	5298[21]	
Oxygen	8	15.9994	0.001429[29] (at 273.2 K and 1 atm)	b.c. orthorh.[7] (α) r.[7] (β) c.[7] (γ)	23.86[21] (α-β) 43.79[21] (β-γ)					250[4] (at ~125 K) 500[36] (at ~250 K)	54.35[21]	90.188[37]	154.8[15]
Palladium	46	106.4	12.02[28]	f.c.c.[10]					283 ± 16[3]	275[3]	1827[37]	3243[21]	
Phosphorus	15	30.97376	1.82[29] (β) 2.22[29] (γ) 2.69[29] (δ)	u. ?[7] (α) b.c.c.[7] (β) c.[7] (γ) f.c. orthorh.[17] (δ)	196[71] (α-β) 298.16[13] (β-γ) 298.16[13] (β-δ)				193[3] (white) 325[3] (red)	576[3] (white) 800[3] (red)	317.3[16] (white) 1300[82] (black)	550[21]	993.8[15]
Platinum	78	195.09	21.45[29]	f.c.c.[10]					234 ± 1[3]	225 ± 5[3]	2042[87]	4109[21]	8310[15]

Name	Atomic Number	Atomic Weight[b]	Density[c], kg m^{-3} x 10^{-3}	Crystal Structure	Phase Transition Temp., K	Superconducting Transition Temp., K	Curie Temp., K	Néel Temp., K	Debye Temperature		Melting Point, K	Boiling Point, K	Critical Temp., K
									At 0 K, K	At 298 K, K			
Plutonium	94	(242)	19.737[29] (at 298.2 K)	Simple monocl.[10] (α) b.c. monocl.[10] (β) f.c. orthorh.[10] (γ) f.c.c.[10] (δ) b.c.t.[10] (δ') b.c.c.[10] (ϵ)	395 ± 2[21] (ϵ-β) 480 ± 5[21] (β-γ) 588 ± 5[21] (γ-δ) 730 ± 5[21] (δ-δ') 753 ± 5[21] (δ'-ϵ)			60[8,83] (α)	171[70]	176[70]	913 ± 1[21]	3510[21]	
Polonium	84	(210)	9.3[29] (α) 9.5[29] (β)	Simple c.[10] (α) r.[10] (β)	327 ± 1.5[66] (α-β)				81[3]		527[16]	1236[20]	2284[15]
Potassium	19	39.098	0.87[16]	b.c.c.[10]					89.4 ± 0.5[3]	100[3]	336.35 ± 0.5[21]	1032[21]	2454[11] 2144[49]
Praseodymium	59	140.9077	6.48[16]	Double c.p.h.[10] (α) b.c.c. (β)	1069 ± 3[21] (α-β)			25[65]	85 ± 1[45]	138[63]	1205 ± 4[21]	3785[21]	8930[49]
Promethium	61	(145)		h.[7] (α) b.c.c.[38] (β)	1185[38] (α-β)			6[38]			1353 ± 10[62]	2734[3]	
Protactinium	91	231.0359	15.37[42]	b.c.t.[10]		1.4[21]			159[3]	262[3]	1505[5]	4692[3]	
Radium	88	226.0254	5[29]						89[3]		973[16]	1900[3]	
Radon	86	(222)	0.00973[29] (at 273.2 K and 1 atm)	f.c.c.[9]						400[4] (at ~200 K)	202[16]	211[21]	377.16[15]
Rhenium	75	186.2	21.1[42]	c.p.h.[10]		1.700 ± 0.002[21]			429 ± 22[3]	275[23]	3459 ± 20[21]	5882[21]	20100[11]
Rhodium	45	102.9055	12.45[42]	f.c.c.[10]	possible transformation at 1373-1473 K[57]				480 ± 32[3]	350[3]	2236[37]	3978[21]	
Rubidium	37	85.4678	1.53[29]	b.c.c.[10]					54 ± 4[3]	59[23]	312.64 ± 0.5[21]	961[21]	2105[41,46,48]
Ruthenium	44	101.07	12.2[29]	c.p.h.[10]		0.49[16]			600[67]	415[3]	2523 ± 10[69]	4433[21]	2035[49]
Samarium	62	150.4	7.54[29]	r.[10] (α) b.c.c.[32] (β)	1191[32] (α-β)		14[8] (ferro.-antiferromag.)	106[8]	116[45]	184 ± 4[3]	1346[61]	2064[16]	5415[49]
Scandium	21	44.9559	3.00[42]	c.p.h.[10] (α) b.c.c.[10] (β)	1610[21] (α-β)				470 ± 80[52]	476[3]	1814[12]	3547[21]	
Selenium	34	78.96	4.50[29] (α) 4.80[29] (β)	monocl.[10] (α) h. (β) amorphous[7]	304[40,60] (vitrification) 398[13] (vit.-β) 423[13] (α-β)				*151.7 ± 0.4*[58]	*89*[36] (at ~45 K) 150[4] (at ~75 K)	*494*[21]	*1009*[13] (Se_6) 956.0[13] ($Se_{4,37}$) 1027[13] (Se_2)	*1759*[15]
Silicon	14	28.086	2.42[16]	d.[10]					647 ± 11[3]	692[3]	1687 ± 2[21]	2753[28]	5172[15]
Silver	47	107.868	10.492[16]	f.c.c.[10]					228 ± 3[3]	221[3]	1235.08[37]	2440[21]	7485[11]
Sodium	11	22.98977	0.9712[16]	b.c.c.[10]	Martensitic transformation at low temp.[56]				157 ± 1[3]	155 ± 5[3]	371.0[21]	1157[21]	2805[11] 2405[49]

Name	Atomic Number	Atomic Weight[b]	Density[c], kg m^{-3} x 10^{-3}	Crystal Structure	Phase Transition Temp., K	Superconducting Transition Temp., K	Curie Temp., K	Néel Temp., K	Debye Temperature		Melting Point, K	Boiling Point, K	Critical Temp., K
									At 0 K, K	At 298 K, K			
Strontium	38	87.62	2.60 [28]	f.c.c. [10] (α) b.c.c. [10] (γ)	830 [21] (α-γ)				147 ± 1 [22]	148 [23]	1042 [21]	1652 [21]	3064 [15] 3818 [49]
Sulfur	16	32.06	2.07 [29] (α) 1.96 [28] (β)	orthorh. [10] (α) monocl. [10] (β) r. [10] (γ)	368.64 [21] (α-β)				200 [3] (β)	527 [55] (α) 250 [55] (α, at 40 K)	386.0 [5] (α) 392.2 [5] (β) subl. 368.6 [13]	717.824 [37]	1314 [15]
Tantalam													
Technetium	43	(99)	11.50 [29]	c.p.h. [10]		8.22 [16]			351 [3]	422 [3]	2451 [16]	4550 [21]	
Tellurium	52	127.60	6.24 [28] (α) 6.00 [5] (amorph.)	h. [10] (α)					141 ± 12 [3]		722.7 [16]	1262 [21]	2332 [15]
Terbium	65	158.9254	8.25 [29]	c.p.h. [10] (α) b.c.c. [10] (β)	1562 [21] (α-β)		219 [80] (ferro.-antiferromag.)	230 [80]	150 [5]	158 [44]	1632 [12]	3503 [16]	
Thallium	81	204.37	11.85 [29]	c.p.h. [10] (α) b.c.c. [10] (β)	507 ± 2 [21] (α-β)	2.39 [16] 2.38 [8]			88 ± 1 [3]	96 [14]	577 ± 2 [21]	1748 [21]	3225 [15]
Thorium	90	232.0381	11.7 [42]	f.c.c. [10] (α) b.c.c. [10] (β)	1636 ± 10 [21] (α-β)	1.368 [16]			170 [84]	100 [14]	2028 [21]	5073 [21]	14600 [49]
Thulium	69	168.9342	9.32 [29]	c.p.h. [10] (α) b.c.c. [10] (β)	Near m.p. [50] (α-β)			53 [81]	127 ± 1 [45]	167 [44]	1820 [12]	2220 [16]	6448 [49]
Tin	50	118.69	5.750 [29] (α) 7.31 [29] (β)	f.c.c. [10] (α) b.c.t. [10] (β)	286.2 ± 3 [51] (α-β)	3.722 [16] (β)			236 ± 24 [3] (gray) 196 ± 9 [3] (white)	254 [3] (gray) 170 [14] (white)	505.1181 [37]	2881 [21]	8030 [11] 9335 [49]
Titanium	22	47.90	4.5 [29]	c.p.h. [10] (α) b.c.c. [10] (β)	1156 [21] (α-β)	0.39 [16] 0.42 [16]			426 ± 5 [3]	380 [14]	1946 ± 3 [21]	3569 [21]	
Tungsten	74	183.85	19.3 [29]	b.c.c. [10]		0.012 [16]			388 ± 17 [3]	312 ± 3 [3]	3660 [37]	5844 [21]	23200 [11]
Uranium	92	238.029	19.07 [28]	orthorh. [10] (α) t. [10] (β) b.c.c. [10] (γ)	37 ± 2 [30] (α_0-α) 941 ± 2 [21] (α-β) 1048 ± 2 [21] (β-γ)	0.68 [16] (α) 0.8 [33] (β) 1.80 [5] (γ)			200 [84]	300 [3]	1407.1 ± 0.6 [85]	4417 [21]	12550 [27] 12050 [49]
Vanadium	23	50.941	6.1 [28]	b.c.c. [10]		5.3 [16] 5.37 [16]			326 ± 54 [3]	390 [14]	2202 ± 6 [21]	3689 [21]	11250 [49]
Xenon	54	131.30	0.005851 [29] (at 273.2 K and 1 atm)	f.c.c. [9]							161.36 [21]	165.03 [21]	289.75 [15]
Ytterbium	70	173.04	7.02 [42]	f.c.c. [10] (α) b.c.c. [10] (β)	1033 [21] (α-β)				118 [78]		1098 [12]	1467	4430 [49]
Yttrium	39	88.9059	4.47 [29]	c.p.h. [10] (α) b.c.c. [10] (β)	1754 [21] (α-β)				268 ± 32 [3]	214 [79]	1800 [86]	3618 [21]	8983 [49]
Zinc	30	65.38	7.140 [29]	c.p.h. [10]		0.825 [21] 0.875 [21]			316 ± 20 [3]	237 ± 3 [3]	692.73 [37]	1181 [21]	2172 [15]
Zirconium	40	91.22	6.57 [50]	c.p.h. [10] (α) b.c.c. [10] (β)	1137 ± 5 [21] (α-β)	0.546 [16]					2127 [21]	4693 [21]	2915 [49] 12800

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Table VIII. Crystal Structures, Densities, and Melting Points of Inorganic Compounds[a]

Name	Crystal[b] Structure	Density,[c] kg m^{-3} x 10^3	Melting Point,[d] K
Simple Oxides			
Al_2O_3	r., h.	3.965	2319 [3] (2323)
BaO	c.	5.72	2196 [3] (2199)
BeO	t., h.	3.01	2843 [3] (2848)
CdO	c.	8.15	1099 [3] (1100)[f]
CaO	c.	3.25-3.38	2864 [3] (2869)
CeO_2	c.	7.132	2670 [3] (2674)
Cr_2O_3	h.	5.21	2573 [3] (2577)
CoO	c., h., t.	6.45	2078 [3] (2081)
D_2O	h. [2]	1.105	277.15 [3] (277.15)
Dy_2O_3	c.	7.81	2658 [3] (2662)
Er_2O_3	c.	8.64	2673 [3] (2677)
EuO	c.		>1973 [3] (1976)
Eu_2O_3	c., monocl.	7.42	2603 [3] (2607)
Gd_2O_3	c., monocl.	7.407	2668 [3] (2672)
GeO_2 (Quartz)	trig.	4.228	1389 [3] (1391)
GeO_2 (Rutile)	t.	6.239	1359 [2] (1361)
HfO_2	t., monocl.	9.68	3063 [3] (3068)
Ho_2O_3	c.		2668 [3] (2672)
H_2O	h. [2]	1.00	273.15 [3] (273.15)
In_2O_3	c.	7.179	2273 [3] (2276)
IrO_2	t.	3.15	1373 [3] (1374)[e]
FeO	r., c.	5.7	1641 [3] (1643)
Fe_2O_3	h., c.	5.24	1835 [3] (1837)
Fe_3O_4	c., r., orthrh.	5.18	1811 [3] (1813)[e]
La_2O_3	c., h.	6.51	2573 [3] (2577)
Lu_2O_3	c.	9.42	2740 [3] (2744)
MgO	c.	3.58	3073 [3] (3078)
MnO	c., r.	5.43-5.46	2058 [3] (2061)
MnO_2	t., orthrh.	5.026	1120 [3] (1121)
Mn_2O_3	c., t.	4.50	1620 [3] (1622)[e]
Nd_2O_3	c., h., monocl.	7.24	2588 [3] (2592)
NiO	c., r.	6.67	2230 [3] (2233)
Nb_2O_5	monocl.	4.47	1783 [3] (1785)
PuO_2	c.	11.46	2513 [3] (2517)
Pr_2O_3	c., h.	6.32 [66]	2563 [3] (2567)
Pr_6O_{11}	c.		2315 [3] (2318)
RuO_2	t.	6.97	1400 [3] (1402)[e]
Sm_2O_3	monocl., c.	8.347	2593 [3] (2597)
Sc_2O_3	c.	3.864	2678 [3] (2682)
SiO_2 (cryst)	monocl., t.	2.19-2.66	1993 [3] (1996)
SiO_2 (fused)		2.17-2.20	

[a] These are the inorganic compounds covered in this volume for which information is available. Superscript numbers in the table designate references listed at the end of the table.

[b] Crystal structures are taken from Ref. [1] unless other reference is given.

[c] Densities are taken from Ref. [2] unless other reference is given.

[d] Melting points given in parentheses have been converted to the International Practical Temperature Scale of 1968 (IPTS-68).

[e] Decomposition temperature.

[f] Sublimation temperature.

Name	Crystal[b] Structure	Density,[c] kg m^{-3} x 10^3	Melting Point,[d] K
Simple Oxides (cont.)			
SrO	c.	4.7	2703 [3] (2707)
Ta_2O_5	monocl.	8.2	2150 [3] (2153) [e]
ThO_2	c.	9.86	3573 [3] (3580)
Tm_2O_3	c.	8.96 [66]	2648 [5] (2652)
SnO_2	t.	6.95	1898 [3] (1900)
TiO	c., t.	4.93	2010 [3] (2013)
TiO_2	t.	4.26	2128 [3] (2131)
Ti_2O_3	r., h.	4.60	2400 [3] (2404)
WO_2	c.	12.11	1843 [3] (1845)
WO_3	monocl., orthrh.	7.16	1743 [3] (1745)
UO_2	c.	10.96	3033 [3] (3033)
U_3O_8	orthrh.	8.3	1723 [3] (1725) [e]
U_4O_9	c.	11.20 [1]	
VO_2	monocl., t.	4.339	1818 [3] (1820)
V_2O_5	orthrh.	3.357	943 [3] (943)
Yb_2O_3	c.	9.17	2693 [3] (2697)
Y_2O_3	c.	5.01	2683 [65] (2687)
ZnO	h.	5.606	2248 [3] (2251) [e]
ZrO_2	c., monocl.	5.89	2963 [3] (2967)
Complex Oxides			
$Dy_2O_3 \cdot 2Al_2O_3$		6.05 [6]	2093 [6] (2096)
$MgO \cdot Al_2O_3$		3.28 [7]	
$Li_2O \cdot GeO_2$		3.51 [8]	1791 [8] (1793)
$Li_2O \cdot 7GeO_2$		3.96 [8]	1578 [8] (1580)
$2Li_2O \cdot GeO_2$		2.57 [8]	1826 [8] (1828)
$3Li_2O \cdot 2GeO_2$		2.88 [8]	1670 [8] (1672)
$3Li_2O \cdot 8GeO_2$		4.20 [8]	1498 [8] (1500)
$CaO \cdot HfO_2$	orthrh. [9]		
$SrO \cdot PbO_2$	orthrh. [10]		
$Gd_2O_3 \cdot 3MoO_3$	orthrh. [11]		
$Dy_2O_3 \cdot Nb_2O_5$		5.493 [6]	2123 [6] (2126)
$LiO \cdot Nb_2O_5$	trig., [12] h. [13]		
$K_2O \cdot Nb_2O_5$	orthrh., [14]		
	t., [14] c. [14]		
$Na_2O \cdot Nb_2O_5$	orthrh. [15]		
	t., [15] c. [15]		
$PbO \cdot Ta_2O_5$	orthrh. [16]		
$Li_2O \cdot Ta_2O_5$	h. [13]		
$K_2O \cdot Ta_2O_5$	c. [18]		
$BaO \cdot TiO_2$		5.28 [19]	
$Cr_2O_3 \cdot V_2O_5$	orthrh. [20]		
$BaO \cdot ZrO_2$	c. [21]	6.73 [22]	
$CdO \cdot ZrO_2$		6.38 [22]	
$CaO \cdot ZrO_2$		4.95 [22]	
$SrO \cdot ZrO_2$	orthrh. [21]	5.42 [23]	3023 [23] (3028)
Arsenates			
$NH_4H_2AsO_4$	orthrh. [25]	2.311	
KD_2AsO_4	orthrh. [25], t. [25]		
KH_2AsO_4	orthrh. [25], t. [25]	2.867	561 [2] (561)
RbD_2AsO_4	orthrh. [25], t. [25]		
Arsenides			
Cd_3As_2	t.	6.21	994 [2] (994)
GaAs	c.		1511 [2] (1513)

Name	Crystal[b] Structure	Density,[c] kg m^{-3} x 10^3	Melting Point,[d] K
Arsenides (cont.)			
InAs	c.		1216 [2] (1217)
MnAs	h., orthrh.	6.17-6.20	674 [2] (674)[e]
Zn_3As_2	t.	5.528	1288 (1289)
Borides			
CrB_2	h. [26]		2423 [27] (2427)
Co_2B	b.c.t.	8.33 [1]	1538 [40] (1540)
DyB_{12}	c.	4.60 [66]	
ErB_{12}	f.c.c. [28]	4.71 [66]	
HfB_2	h.	10.5 [1]	3473 [40] (3480)
HoB_{12}	f.c.c. [28]	4.65 [66]	
Fe_2B	b.c.t.	7.0 [1]	1662 [48] (1664)
LuB_{12}	c.	4.87 [66]	
MoB_2	h.	7.12	2373 [48] (2377)
NbB_2	h.	6.97	3173 [2] (3179)
			3323 [48] (3329)
SmB_6	c.	5.07 [66]	2850 [66] (2855)
ScB_2	h.	3.67 [66]	2523 [40] (2527)
SiB_6	orthrh.	2.32 [30]	2220 [66] (2223)
SiB_4	h.	2.08 [30]	
TaB	orthrh.	14.0 [1]	3073 [40] (3078)
TaB_2	h. [29]	11.15	3423 [40] (3429)
TbB_{12}	c.	5.39 [66]	2610 [66] (2614)
TiB_2	h.	4.50	3173 [2] (3179)
			3253 [17] (3259)
TmB_{12}	c.	4.75 [66]	
VB_2	h.	5.10	2673 [48] (2677)
YbB_{12}	c.	4.83 [66]	
YB_{12}	c.	3.44 [66]	2470 [66] (2474)
ZrB_2	h.	6.085	3313 [40] (3319)
ZrB_{12}	c.	3.7 [1]	2953 [40] (2958)
Bromates			
$NaBrO_3$	c. [2]	3.339	654 [2] (654)
Bromides			
CsBr	c. [2]	4.44	909 [2] (909)
CuBr	c. [2]	4.98	765 [2] (765)
$PbBr_2$	orthrh. [31]	6.66	646 [2] (646)
LiBr	c. [2]	3.464	820 [2] (820)
$MnBr_2 \cdot 4H_2O$	monocl. [2], r. [2]		
KBr	c. [2]	2.75	1003 [2] (1003)
RbBr	c. [2]	3.35	955 [2] (955)
AgBr		6.473	705 [2] (705)
NaBr	c. [2]	3.203	1028 [2] (1028)
TlBr	c. [2]	7.557	753 [2] (753)
Carbides			
B_4C	h.	2.52	2743 [32] (2747)
Cr_3C_2	orthrh.	6.68	2300 [33] (2303)
HfC	f.c.c.	12.20	4164 [2] (4172)
Mo_2C	h.	8.90	2960 [2] (2965)
NbC	f.c.c.	7.60	3772 [2] (3780)
PuC	f.c.c.		
SiC	c., h., r.	3.217	3245 [32] (3251)[e]
TaC	f.c.c.	13.9	4153 [2] (4162)
ThC_2	monocl.	8.96	2928 [2] (2932)

Name	Crystal[b] Structure	Density,[c] kg m^{-3} x 10^3	Melting Point,[d] K
Carbides (cont.)			
TiC	f.c.c.	4.93	3413 [2] (3419)
WC	h.	15.63	3142 [2] (3148)
UC	f.c.c.	13.6 [66]	2797 [33] (2802)
UC_2	c., t.	11.28	2648 [2] (2652)
U_2C_3	b.c.c.	12.7 [1]	
VC	f.c.c.	5.7	3083 [2] (3088)
ZrC	f.c.c.	6.73	3107 [32] (3113)
Carbonates			
$CaCO_3$	r. [2], h. [2]	2.930	1612 [2] (1614)
$CoCO_3$	trig. [2]	4.13	
$FeCO_3$	trig. [2]	3.8	
$MgCO_3$	trig. [2]	2.958	623 [2] (623)[e]
$MnCO_3$	r. [2]	3.125	
$NiCO_3$	r. [2]		
Chlorides			
NH_4Cl	c. [2]	1.527	613 [2] (613)[f]
CsCl	c. [2]	3.988	919 [35] (919)
$CoCl_2 \cdot 6H_2O$	monocl. [34]	1.924	
CuCl	c. [2]	4.14	703 [2] (703)
$PbCl_2$	r. [2]	5.85	774 [2] (774)
LiCl	c. [2]	2.068	887 [2] (887)
$MnCl_2 \cdot 4H_2O$	monocl. [2]	2.01	331 [2] (331)
KCl	c. [2]	1.984	1049 [2] (1050)
RbCl	c. [2]	2.80	988 [2] (988)
AgCl	c. [2]	5.56	728 [2] (728)
NaCl	c. [2]	2.165	1074 [2] (1075)
$SrCl_2$	c. [2]	3.052	1146 [2] (1147)
TlCl		7.004	703 [2] (703)
Chlorates			
$NaClO_3$	c. [2], trig. [2]	2.490	528 [2] (528)
Fluorides			
BaF_2	c. [2]	4.89	1553 [2] (1555)
CdF_2	c. [2]	6.64	1373 [2] (1374)
CaF_2	c. [2]	3.180	1633 [2] (1635), 1775 [37] (1777)
CsF	c. [2]	4.115	955 [2] (955)
CoF_2	monocl. [2]	4.46	1473 [2] (1475)
FeF_2	r. [2]	4.09	1374 [32] (1375)
LaF_3			1761 [38] (1763)
PbF_2	r. [2]	8.24	1128 [2] (1129)
LiF	c. [2]	2.635	1115 [2] (1116)
MgF_2	t. [2]	3.18 [36]	1539 [2] (1541)
MnF_2	t. [2]	3.98	1029 [2] (1030)
NiF_2	t. [2]	4.63	1273 [2] (1274)[f]
KF	c. [2]	2.48	1019 [2] (1020)
RbF	c. [2]	3.557	1048 [2] (1049)
NaF	c., t. [2]	2.558	1261 [2] (1262)
SrF_2	c. [2]	4.24	>1723 [2] (1725)
TlF	c. [2]	8.23	600 [2] (600)
ZnF_2	monocl. [2], tricl. [2]	4.95	1145 [2] (1146)

Name	Crystal[b] Structure	Density,[c] kg m^{-3} x 10^3	Melting Point,[d] K
Hydrides			
LiH		0.82	953 [2] (953)
LiD		0.8841 [39]	
TiH_2	f.c.c.	3.9	673 [2] (673)[e]
YbH_2	orthrh.		
ZrH_2	b.c.t. [33]		
Iodates			
$NaIO_4$	t. [2]	3.865	573 [2] (573)[e]
Iodides			
CdI_2		5.670	660 [2] (660)
CsI	r. [2]	4.510	894 [2] (894)
CuI	c. [2]	5.62	878 [2] (878)
PbI	h. [31]		573 [2] (573)[e]
HgI_2	t. [31]	6.36	
KI	c. [2]	3.13	959 [2] (959)
RbI	c. [2]	3.55	915 [2] (915)
AgI	c. [2]	6.010	831 [2] (831)
NaI	c. [2]	3.667	924 [2] (924)
TlI	r. [2], c. [2]	7.29	713 [2] (713)
TlI_4	c. [2]	4.30	423 [2] (423)
Nitrates			
NH_4NO_3	r. [2]	1.725	443 [2] (443)
$Ba(NO_3)_2$	c. [2]	3.24	865 [2] (865)
$Pb(NO_3)_2$	c. [2], monocl. [2]	4.53	743 [2] (743)[e]
$RbNO_3$	c. [2], r. [2], tricl. [2]	3.11	583 [2] (583)
$AgNO_3$	r. [2]	4.352	481 [41] (481)
$NaNO_3$	r. [2], trig. [2]	2.261	581.7 [41] (581.7)
$Sr(NO_3)_2$	c. [2]	2.986	843 (843)
Nitrides			
AlN	h.	3.26	~2673 [44] (2677)
BN	h. [2], c. [67]	2.25 (h.)	~3273 [2] (3279)[f]
HfN	c.	12.4 [43]	3578 [2] (3585)
NpN	c. [42]		
NbN	c. [2]	8.4	2847 [2] (2852)
PuN	c.	14.25	
Si_3N_4	h.	3.44	2173 [44] (2176)[e]
TaN	h.	16.3	3361 [45] (3367)
TiN	c.	5.22	3203 [2] (3209)
UN	c.	14.31	2903 [2] (2907)
VN	c.	6.13	2593 [2] (2597)
ZrN	c.	7.09	3253 [2] (3259)
Nitrites			
$NaNO_2$	r. [2]	2.168	553 [41] (553)
Phosphates			
$AlPO_4$	r. [2]	2.566	>1773 [2] (1775)
$NH_4H_2PO_4$	orthrh. [25,46]	1.803	
	t. [25,46]		
$CO_3(PO_4)_2$		2.587	
KD_2PO_4	orthrh. [25], t. [25]		
KH_2PO_4	orthrh. [25], t. [25]	2.338	525.8 [2] (525.8)
$Sn_3(PO_4)_2$		3.823	
$Zn_3(PO_4)_2$	r. [2]	3.998	

Name	Crystal[b] Structure	Density,[c] kg m^{-3} x 10^3	Melting Point,[d] K
Phosphides			
BP	c. [47]		
GaP	c.		1623 [49] (1625)
InP	c.		1343 [2] (1344)
Fe_3P	t.	6.74	1373 [2] (1374)
MnP	orthrh.	5.39	1463 [2] (1464)
NpP	c. [42]		
Selenides			
As_2Se_3	monocl.	4.75	633 [2] (633)
CdSe	c.	5.81	>1623 [2] (1625)
Ga_2Se_3	c.	4.92	1293 [2] (1294)
HgSe	c.	8.266	
Pr_2Se_3	c.	5.27 [1]	
USe	c. [48]		
ZnSe	c. [2]	5.42	>1373 [2] (1374), 1799 [50] (1801)
Selenites			
$KH_3(SeO_3)_2$	r. [51]		
Silicates			
Ca_2SiO_4	r. [2], monocl. [2]	2.97-3.28	2406 [2] (2410)
Ca_3SiO_5	monocl. [2]		2173 [2] (2176)
Co_2SiO_4	r. [2]	4.63	1618 [2] (1620)
Fe_2SiO_4	r. [2]	4.34	
$PbSiO_3$	monocl. [2]	6.49	1040 [2] (1040)
Li_4SiO_4	r. [2]	2.392	1529 [2] (1531)
$MgSiO_3$	monocl. [2]	3.192	1830 [2] (1832)[e]
Mg_2SiO_4	orthrh. [2]	3.21	2183 [2] (2186)
$MnSiO_3$	tricl. [2]	3.72	1601 [2] (1603)
$RbAl(SiO_3)_2$	t. [52], c. [52]		
Zn_2SiO_4	trig. [2]	4.103	1882 [2] (1884)
$ZrSiO_4$	t. [2]	4.56	3823 [2] (3830)
Silicides			
$BaSi_2$	h.	3.87 [1]	
CrSi	c.		~1873 [4] (1875)
$CrSi_2$	h.	4.91 [1]	~1748 [17] (1750)
Cr_3Si	c.		~2043 [17] (2046)
Cr_3Si_2	t. [2]	5.5	
CoSi	c.	6.506 [1]	1668 [2] (1670)
Cu_5Si	c.	7.9 [1]	
FeSi	octhedr. [2]	6.1	1683 [48] (1685)
$FeSi_2$	b.c.t.	4.54 [1]	1484 [48] (1486)
$LaSi_2$	t.	5.1 [1]	1793 [17] (1795)
Mg_2Si	c.	1.94 [2]	1374 [32] (1376)
MnSi	c.	5.90	1548 [17] (1550)
Mo_3Si	c.		2406 [48] (2410)
$MoSi_2$	t.	6.31	2223 [48] (2226)
Mo_5Si_3	h.	8.14 [1]	
Ni_2Si	orthrh	7.2	1591 [48] (1593)
Nb_5Si_3	t.		2753 [48] (2757)
$ReSi_2$	t.	10.7 [1]	
$TiSi_2$	orthrh. [33]		1813 [33] (1815)
Ti_5Si_3	h. [33]		2393 [33] (2396)
WSi_2	t.	9.4	2450 [53] (2437)
U_3Si	t.	15.60 [1]	1203 [54] (1204)

Name	Crystal[b] Structure	Density,[c] kg m^{-3} x 10^3	Melting Point,[d] K
Silicides (cont.)			
β-USi_2	h.		1973 [54] (1976)
V_3Si	c.		
VSi_2	h.	4.42	1930 [55] (1933)
V_5Si_3	h.	5.27 [1]	2423 [56] (2427)
$ZrSi_2$	orthrh.	4.88	
Sulfates			
Cs_2SO_4	orthrh. [57], h. [57]	4.243	1283 [2] (1284)
Li_2SO_4	monocl. [58, 59]		
	f.c.c. [58, 59]		
$Li(N_2H_5)SO_4$	orthrh. [60]		
K_2SO_4	orthrh. [61], h. [61]	2.662	1963 [2] (1965)
Rb_2SO_4	r. [2], h. [2]	3.613	
Na_2SO_4	orthrh. [62], h. [62]		1157 [32] (1158)
Sulfides			
BaS	c.	4.32 [1]	1473 [2] (1475)
CdS	c., h.	4.82	1253 [48] (1254)
CaS	c.	2.5	
CeS	c.	5.93 [1]	
Ce_2S_3	c.	5.25	
EuS	c.	5.71 [1]	
LaS	c.		1873 [48] (1875)
La_2S_3	c.	4.911	2398 [2] (2402)
MnS	c., h.	3.99	
MoS_2	h., r.	4.92 [1]	1469 [2] (1470)
NdS	c.		
Nd_2S_3	c.	5.49 [1]	
P_4S_3	r., orthrh. [63]	2.03	
PuS	c.	10.6 [1]	
PrS	c.		
Pr_2S_3	c.	5.27 [1]	
Sm_2S_3	c.	5.729	2173 [2] (2176)
SrS	c.	3.70	2273 [2] (2276)
ZnS	c., h.	3.98	2103 [64] (2106)
Tellurides			
BiTe	c.		
CdTe	c.	5.866	1314 [2] (1315)
CrTe	h.		
GeTe	r., c. [4, 65]	6.20 [1]	998 [48] (998)
InTe	t.	6.29	969 [2] (969)
LaTe	c. [1], monocl.		
PbTe	c.	8.164	1190 [2] (1191)
MnTe	c., h.		
HgTe	c.		
SnTe	c.	6.48	1053 [2] (1054)
ZnTe	c., h.	6.34	1513 [2] (1514)

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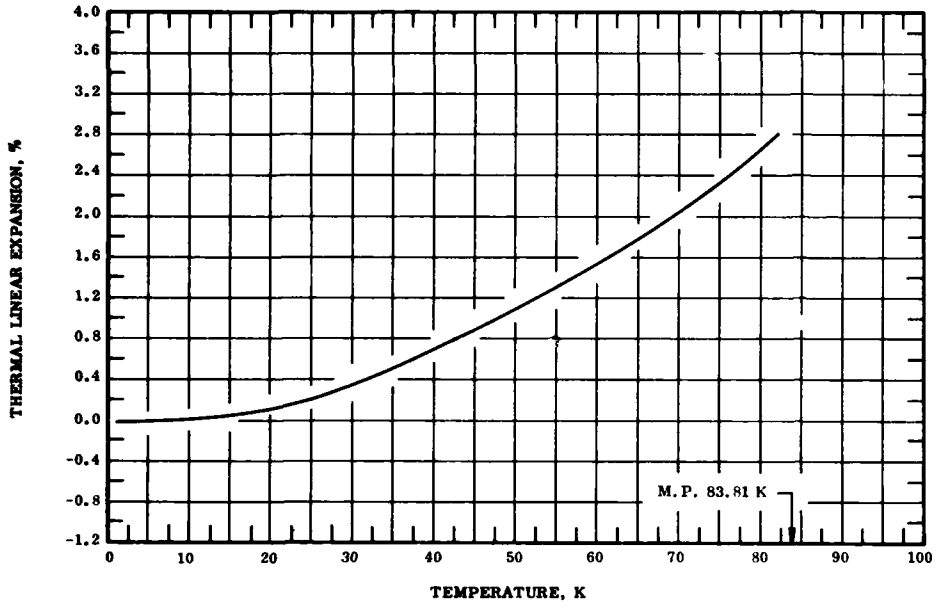
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Numerical Data on Thermal Linear Expansion of Nonmetallic Solids

1. ELEMENTS

FIGURE AND TABLE NO. 1R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF ARGON Ar



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$ [§]	α
1	-0.00025	0.03
2	-0.00023	0.4
3	-0.00017	1.2
4	0.00000	9.4
5	0.0017	22.5
6	0.0045	33.5
7	0.0084	44.3
8	0.013	55.0
9	0.019	65.6
10	0.026	76.1
12	0.044	97.5
14	0.065	117
16	0.091	138
18	0.120	158
20	0.154	177
25	0.254	225
30	0.378	270
35	0.524	314
40	0.692	355
45	0.879	395
50	1.087	43[illegible]
55	1.312	469
60	1.555	503
65	1.814	534
70	2.089	564
75	2.378	592
80	2.681	618
82.5	2.837	630

[§] This curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.

REMARKS

The recommended values are based on the data for single crystals and are considered accurate to within ±3%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = 0.004 - 3.287 \times 10^{-3} T + 5.648 \times 10^{-4} T^2 - 1.317 \times 10^{-6} T^3 \qquad (4\text{-}82.5\ K)$$

The tabulated values for the coefficient of thermal expansion are obtained from the experimental data (curves 3, 5, and 6) and are considered accurate to about ± 5%.

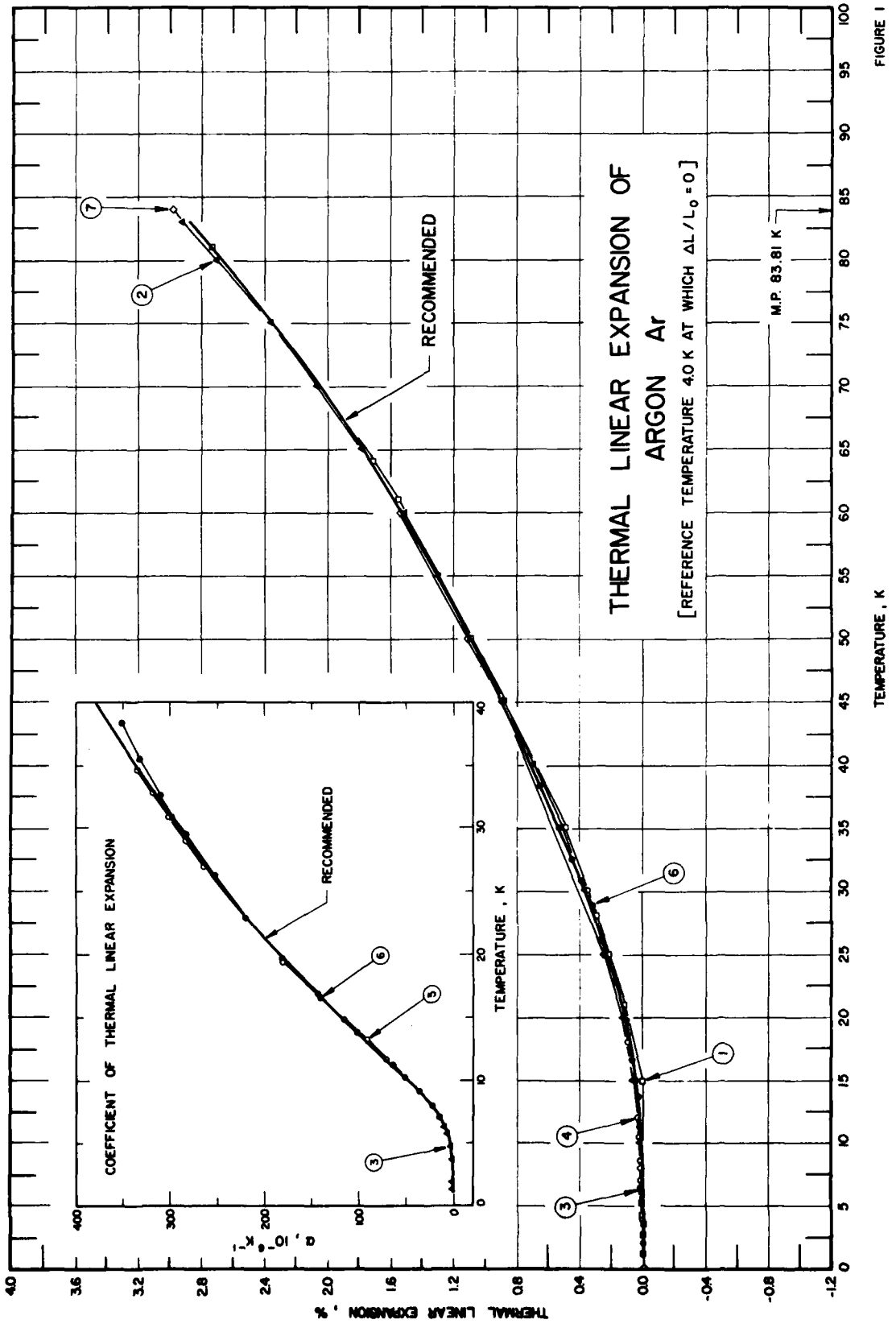

THERMAL LINEAR EXPANSION OF ARGON Ar
[REFERENCE TEMPERATURE 4.0 K AT WHICH ΔL/L₀ = 0]
M.P. 83.81 K
RECOMMENDED
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
RECOMMENDED
TEMPERATURE , K

FIGURE 1

SPECIFICATION TABLE 1. THERMAL LINEAR EXPANSION OF ARGON Ar

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	347	Barrett, C.S. and Meyer, L.	1964	X	4.2-81		Face-centered cubic specimen formed by freezing research-purity material from Matheson Co. in cavity in copper block, lattice constant expansion measured by using CuKα_1, Kα_2, and Kβ radiation with scintillation counter and pulse-height analyzer on fine-grained polycrystalline specimen; 5.3118 Å reported at 4.2 and 15 K; c.p.h. phase coexists with cubic, $A_{hex} = 0.7071\ A_{cubic}$ and $C_{hex} = 1.633\ A_{hex}$ throughout the temperature range; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$; reported error <0.014%.
2	348	Peterson, O.G., Batchelden, D.N., and Simmons, R.O.	1966	X	0-83		99.998 pure crylindrical crystal specimen; prepared by directional solidification of the liquid argon at ~1 mm hr^{-1} with solid-liquid interface being nearly plane; lattice constant expansion measured; lattice constant at 4.0 K is 5.30017 ± 0.00008 Kxu (or 5.28928 ± 0.00008 Å by using reported conversion factor 1.002059) which used as reference point for reported data.
3	349	Tilford, C.R. and Swenson, C.A.	1969	E	1.3-6.4	3rd specimen	0.0002 to 0.0003 O_2; f.c.c. structure specimen consist of three posts 1 cm diameter and 3 cm long which grown from melt in Mylar tubes; reported error 0.75% data on coefficient of thermal linear expansion reported, $\alpha = (3.34\ T^3 + 0.030\ T^5) \times 10^{-8}\ K^{-1}$ $(1 < T < 6\ K)$; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
4	492	Tilford, C.R. and Swenson, C.A.	1972	L	1-35		Specimen 3/8" diameter by 30 mm long, initial length temperature not reported by author; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction is -2.358×10^{-6}%.
5	492	Tilford, C.R. and Swenson, C.A.	1972	L	1-35	Set I	Similar to the above specimen.
6	492	Tilford, C.R. and Swenson, C.A.	1972	L	11-31	Set II	Similar to the above specimen; capacitance cell gap made smaller for second set by heating cell to a temperature greater than initial assembly temperature, this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
7	577	Peterson, O.G.	1965	X	2.3-83.2		Single crystals grown using modified Bridgman technique from research grade argon obtained from Matheson Co.; argon gas nominal 99.998% purity impurity content of CH_4 0.0001%, CO_2 0.0001%, H_2 0.0005%, N_2 0.0005%, and O_2 0.0005%; each smoothed curve value taken from two to six curves; final best crystal was a single 3 mm diameter grain over a distance of 7 mm with approx. min. dislocation density of $10^6/cm^2$; temperature control of the specimen was ± 0.01 K or better for the duration of the x-ray exposures; exposures varied from 10 min to 45 min as the temperature increased; the x-ray beam had lateral angular divergance of 0.4° and struck about 2 mm x 5 mm of crystal surface; measurement error ± 5%; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction is -0.0011%.

DATA TABLE 1. THERMAL LINEAR EXPANSION OF ARGON Ar

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1§

T	$\Delta L/L_0$
4.2	0.0000
15.0	0.0000
21.0	0.1223
21.0	0.1374*
25.0	0.2033
28.0	0.2918
35.0	0.4867
50.0	1.0975
61.0	1.5663
63.0	1.6755*
63.7	1.6924*
64.0	1.7169
64.0	1.7282*
81.0	2.752

CURVE 2§

T	$\Delta L/L_0$
4	0.0000*
6	0.0005
8	0.0037*
10	0.0106
12	0.0224*
15	0.0500
20	0.1279
25	0.2331
30	0.3645
35	0.5173
40	0.6884
45	0.8752
50	1.0791*
55	1.2989
60	1.5352
65	1.7904
70	2.0672
75	2.3694
80	2.7010
83	2.9155

CURVE 3§

T	$\Delta L/L_0$
1.34	-0.000248
1.64	-0.000244*
1.95	-0.000238*
2.00	-0.000237*
2.14	-0.000231*
2.30	-0.000224*
2.37	-0.000221*

CURVE 3 (cont.)§

T	$\Delta L/L_0$
2.70	-0.000202
2.90	-0.000186*
3.11	-0.000165*
3.48	-0.000116
3.56	-0.000103
3.83	-0.000052*
4.05	0.000000*
4.53	0.000149*
5.07	0.000392
5.72	0.000829*
6.43	0.001538

CURVE 4§

T	$\Delta L/L_0$
1	-0.000235*
1.5	-0.000231*
2	-0.000222
2.5	-0.000202*
3	-0.000164*
3.5	-0.000100*
4	0.000000
4.5	0.000150*
5	0.000366*
5.5	0.000667*
6	0.00108*
6.5	0.00163*
7	0.00233
7.5	0.00322*
8	0.00432*
8.5	0.00565
9	0.00725*
9.5	0.00911*
10	0.0113*
10.5	0.0137
11	0.0165*
12	0.0231
13	0.0310*
14	0.0404*
15	0.0512
16	0.0635*
18	0.0923
20	0.126*
25	0.233*
30	0.364
35	0.517

CURVE 5*,§

T	$\Delta L/L_0$
1.123	-0.000245
1.323	-0.000244
1.595	-0.000240
1.917	-0.000234
1.978	-0.000233
2.257	-0.000223
2.669	-0.000200
3.098	-0.000161
3.548	-0.000097
4.026	0.000005
4.506	0.000157
5.051	0.000409
5.696	0.000851
6.420	0.001594
7.197	0.00277
8.045	0.00461
9.101	0.00787
10.350	0.0134
11.751	0.0221
13.284	0.0347
14.950	0.0523
16.957	0.0790
19.447	0.120
26.989	0.289
28.946	0.344
30.945	0.403
32.982	0.467
34.962	0.532

CURVE 6§

T	$\Delta L/L_0$
11.399	0.0199
13.862	0.0406
16.611	0.0739
19.882	0.127
22.950	0.189
26.243	0.269
26.970	0.288
28.948	0.342
29.530	0.358
30.943	0.399
32.536	0.448
35.518	0.545
38.454	0.646

CURVE 7§

T	$\Delta L/L_0$
0	-0.0011
6	0.0055*
8	0.0038
10	0.0116*
12	0.0236*
15	0.0529*
20	0.1285*
25	0.2338*
30	0.3644*
35	0.5172*
40	0.6876*
45	0.8752
50	1.0789
55	1.2985*
60	1.5349
65	1.7900*
70	2.0668*
75	2.3690*
80	2.7007*
83	2.9152*
84	2.9896

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* Not shown in figure.

§ This curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 1. COEFFICIENT OF THERMAL LINEAR EXPANSION OF ARGON Ar

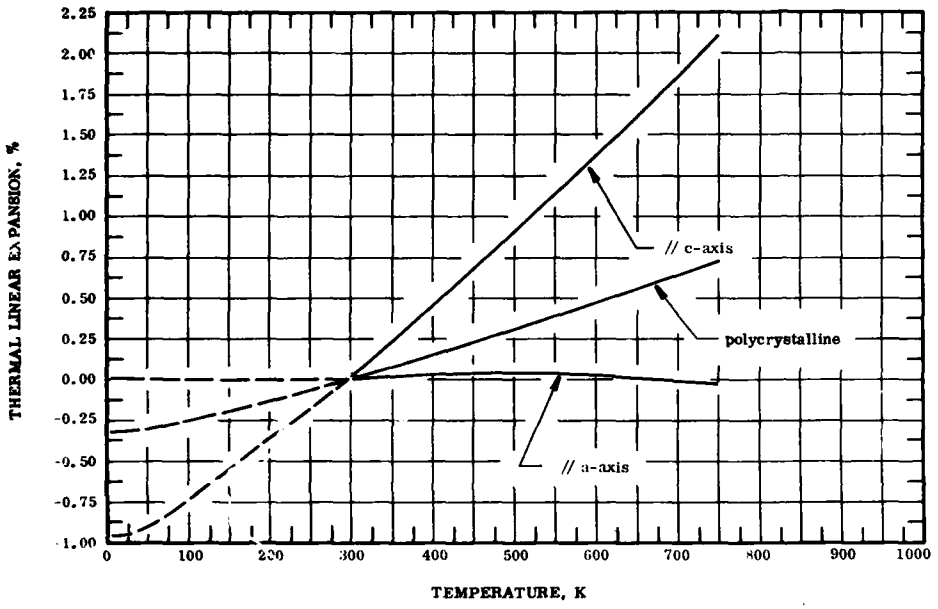
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3	
1.34	0.0810
1.64	0.1554*
1.95	0.2616*
2.00	0.2832
2.14	0.4752*
2.30	0.4230*
2.37	0.4685*
2.70	0.6977*
2.90	0.8818
3.11	1.1041*
3.48	1.5454*
3.56	1.6819
3.83	2.1282*
.05	2.5505*
4.53	3.6589
5.07	5.3683*
5.72	8.0616
6.43	11.9236
CURVE 5	
1.123	0.0443
1.323	0.0804*
1.595	0.147*
1.917	0.256*
1.978	0.283*
2.257	0.412*
2.669	0.695*
3.098	1.124*
3.548	1.720*
4.026	2.587*
4.506	3.726*
5.051	5.50*
5.696	8.23*
6.420	12.29*
7.197	17.96
8.045	25.51
9.101	36.83
10.350	52.3
11.751	71.5
13.284	92.6
14.950	118.5
16.987	147.8
19.447	182.3
26.989	267.9
28.946	286.3

T	α
CURVE 5 (cont.)	
30.945	303.7
32.982	320.7
34.962	336.1
CURVE 6	
11.399	66.1
13.862	101.5
16.611	141.4
19.882	185.4
22.950	222.5
26.243	256.5
26.970	264.4*
28.948	282.5
29.530	286.4
30.943	299.5
32.536	311.3
35.518	333.8
38.454	354.4

* Not shown in figure.

FIGURE AND TABLE NO. 2R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF ARSENIC As



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
5	-0.95 †	0.017 †	-0.305 †	0.02
10	-0.95 †	0.017 †	-0.305 †	0.17
20	-0.94 †	0.016 †	-0.303 †	1.5
30	-0.93 †	0.015 †	-0.300 †	3.6
40	-0.91 †	0.014 †	-0.294 †	5.0
50	-0.88 †	0.010 †	-0.287 †	6.5
100	-0.72 †	0.008 †	-0.235 †	10.9
150	-0.55 †	0.005 †	-0.180 †	12.1
200	-0.36 †	0.003 †	-0.118 †	13.0
250	-0.17 †	0.001 †	-0.056 †	13.5
293	0.000	0.000	0.000	15.4
350	0.249	0.014	0.092	16.0
400	0.470	0.020	0.170	15.5
450	0.697	0.022	0.247	15.4
500	0.929	0.021	0.323	15.3
550	1.170	0.015	0.400	15.4
600	1.419	0.008	0.478	15.8
650	1.679	-0.002	0.558	16.3
700	1.951	-0.013	0.642	17.0
750	2.236	-0.025	0.729	17.3

† Provisional values.

REMARKS

The recommended values for the axial thermal expansion are based on the data for pure samples (curves 3, 6, 8 and 11 for // c-axis; curves 4, 5, 7 and 10 for // a-axis). The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ± 5% at temperatures above 293 K and ± 7% below 293 K and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -1.285 + 4.601 \times 10^{-3} T - 1.277 \times 10^{-6} T^2 + 1.870 \times 10^{-9} T^3$ (293-750 K)

// a-axis: $\Delta L/L_0 = -2.131 + 1.220 \times 10^{-3} T - 1.930 \times 10^{-6} T^2 + 8.508 \times 10^{-10} T^3$ (293-750 K)

polycrystalline: $\Delta L/L_0 = -0.572 + 2.358 \times 10^{-3} T - 1.740 \times 10^{-6} T^2 + 1.213 \times 10^{-9} T^3$ (293-750 K)

The tabulated values for the coefficient of thermal expansion are derived from the experimental data and are considered accurate to about ± 5%.

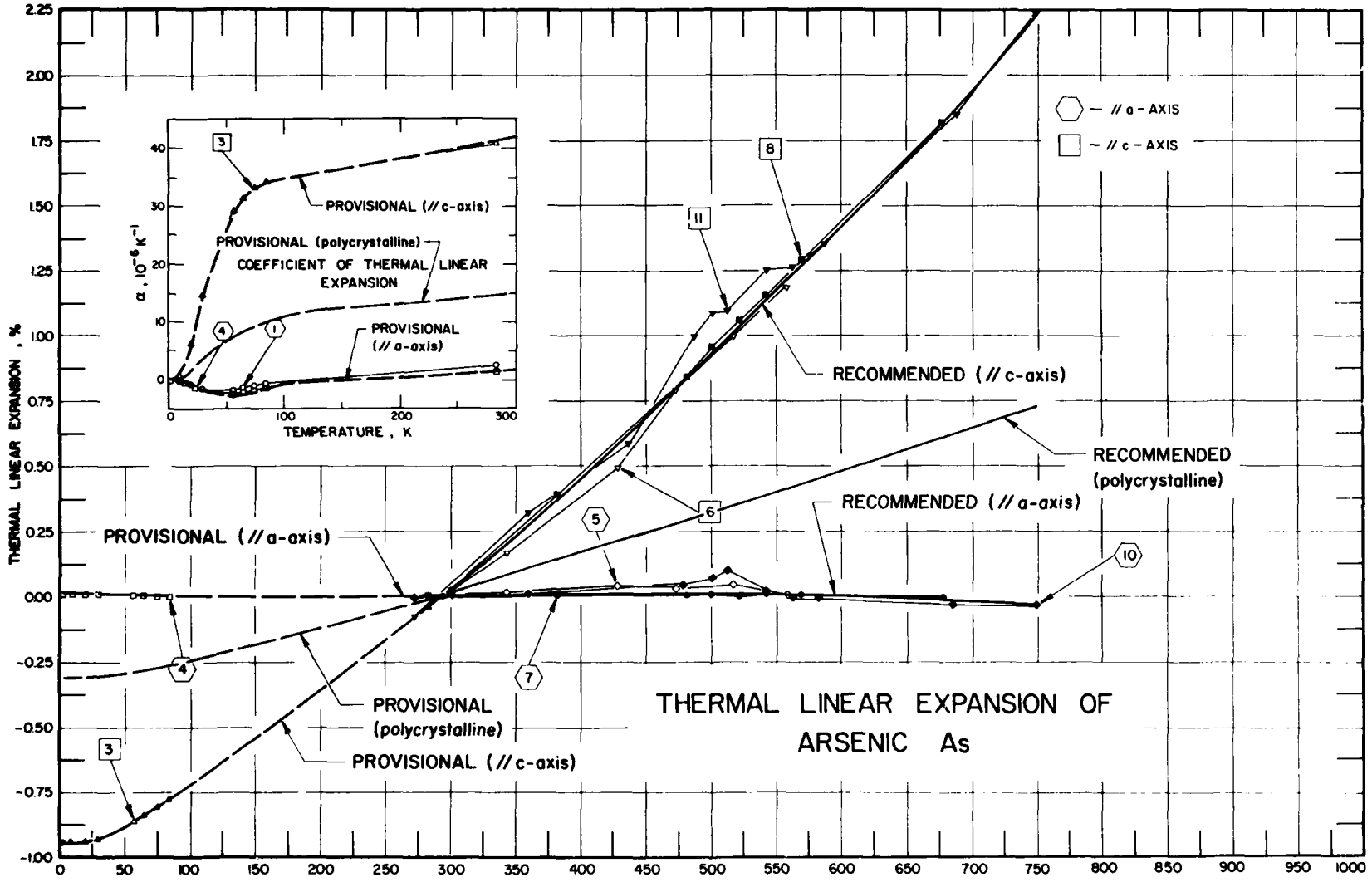

THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
THERMAL LINEAR EXPANSION OF ARSENIC As
// a - AXIS
// c - AXIS
RECOMMENDED (// c-axis)
RECOMMENDED (polycrystalline)
RECOMMENDED (// a-axis)
PROVISIONAL (// a-axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// c-axis)
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K

FIGURE 2

SPECIFICATION TABLE 2. THERMAL LINEAR EXPANSION OF ARSENIC As

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	582	White, G.K.	1972	E	2.5-283	As 1 NRC No. K11	Cylindrical single crystal specimen, 4.48 cm long; ends carefully ground and lapped to flatness and parallelism with z axis of crystal inclined at 80° to the cylinder axis; density 5.77 g cm^{-3} at 293 K.
2*	582	White, G.K.	1972	E	2.5-283	As 2 NRC No. K27	Specimen cut and prepared to a length of 4.48 cm in the same way as above specimen; x-rays showed orientation of single crystal to be 86°.
3	582	White, G.K.	1972	E	2.5-283	As 3 NRC No. K3	Sample cut into pieces and cleaved so as to produce a rod parallel to trigonal axis, individual pieces cut from cylinder to be about 1 cm long, then cleaved with razor blade on two opposite walls, stacked up to give rod 2.6 cm long; zero degree from z axis.
4	582	White, G.K.	1972	E	2.5-283	As 3 NRC No. K3	The above specimen; expansion measured perpendicular to z axis.
5	484	Pawar, R.R. and Deshpande, V.T.	1970	X	301-559		Sample supplied by Thomas Tyrer and Co; a-parameter measured, max value at about 473 K and then falls gradually; a-parameter at 301 K is reported as 3.7585 Å; 3.7584 Å at 293 K determined by graphical extrapolation.
6	484	Pawar, R.R. and Deshpande, V.T.	1970	X	301-559		The above specimen; c-parameter measured; equation for coefficient of thermal expansion was given by authors $\alpha_c = (33.45 \times 10^{-6} + 80.2 \times 10^{-6} t)$ °C with error < 5%; c-parameter at 301 K is reported 10.5564 Å; 10.5536 Å at 293 K determined by graphical extrapolation.
7	485	Taylor, J.B., Benette, S.L., and Heyding, R.D.	1965	X	295.6-677	α-arsenic	Polycrystalline sample containing impurities Pb, Mg, and S each less than 0.2 ppm, heated in vacuo at 623 K; a-lattice dimension of hexagonal unit cell measured; 3.7598 Å at 295.6 K reported; 3.7598 Å at 293 K determined by graphical extrapolation.
8	485	Taylor, J.B., et al.	1965	X	295.6-677	α-arsenic	The above specimen; c-lattice dimension of hexagonal unit cell measured; 10.547 Å at 295.6 K reported; 10.546 Å at 293 K determined by graphical extrapolation.
9*	485	Taylor, J.B., et al.	1965	X	295.6-677		Rhombohedral unit cell dimension measured; 4.1318 Å at 295.6 K reported; 4.1314 Å at 293 K determined by graphical extrapolation.
10	486	Klemm, W., Spitzer, H., and Nierman, H.	1960	X	273-750		Lattice dimension of α polycrystalline specimens measured; hexagonal a-parameter at 273 K is reported as 3.7591 Å; 3.7592 Å at 293 K determined by graphical interpolation.
11	486	Klemm, W., et al.	1960	X	273-750		The above specimen; hexagonal c-parameter at 273 K is reported as 10.549 Å; 10.557 Å at 293 K determined by graphical interpolation.

* Not shown in figure.

DATA TABLE 2. THERMAL LINEAR EXPANSION OF ARSENIC As

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*,‡	
2.5	-0.0114
3	-0.0114
4	-0.0114
5	-0.0114
6	-0.0114
7	-0.0114
8	-0.0114
10	-0.0114
12	-0.0114
14	-0.0115
16	-0.0115
18	-0.0116
20	-0.0118
22	-0.0119
24	-0.0121
26	-0.0124
28	-0.0126
30	-0.0129
57	-0.0175
65	-0.0188
75	-0.0200
85	-0.0208
283	-0.0010
CURVE 2*,‡	
2.5	0.0119
3	0.0119
4	0.0119
5	0.0119
6	0.0119
7	0.0119
8	0.0119
10	0.0119
12	0.0119
14	0.0118
16	0.0117
18	0.0116
20	0.0115
22	0.0113
24	0.0111
26	0.0108
28	0.0105
30	0.0101
57	0.0041
65	0.0022
75	0.0003

T	$\Delta L/L_0$
CURVE 2 (cont.)*,‡	
85	-0.0012
283	-0.0001
CURVE 3‡	
2.5	-0.945
3	-0.945*
4	-0.945*
5	-0.945*
6	-0.945*
7	-0.945*
8	-0.945*
10	-0.945
12	-0.945*
14	-0.945*
16	-0.944*
18	-0.943*
20	-0.942
22	-0.941*
24	-0.939*
26	-0.937*
28	-0.934*
30	-0.932
57	-0.872
65	-0.848
75	-0.816
85	-0.782
283	-0.038
CURVE 4‡	
2.5	0.0168
3	0.0168*
4	0.0168*
5	0.0168*
6	0.0168*
7	0.0168*
8	0.0168*
10	0.0168
12	0.0167*
14	0.0167*
16	0.0166*
18	0.0165*
20	0.0163
22	0.0161*
24	0.0159*

T	$\Delta L/L_0$
CURVE 4 (cont.)‡	
26	0.0156*
28	0.0152*
30	0.0148
57	0.0086
65	0.0065
75	0.0044
85	0.0027
283	0.0001
CURVE 5	
301	0.0027
343	0.0186
428	0.0399
473	0.0293
517	0.0452
559	0.0106
CURVE 6	
301	0.0265
343	0.1677
428	0.4889
473	0.7883
517	0.9921
559	1.1816
CURVE 7	
295.6	0.0000
382	0.0027
482	0.0027
501	0.0080
523	0.0000
543	0.0027
570	0.0027
677	-0.0080
CURVE 8	
295.6	0.0095*
382	0.3889
482	0.8439
501	0.9577
523	1.0620
543	1.1663

T	$\Delta L/L_0$
CURVE 8 (cont.)	
570	1.2896
677	1.8206
CURVE 9*	
295.6	0.0097
382	0.2856
482	0.6148
501	0.6995
523	0.7721
543	0.8496
570	0.9391
677	1.3216
CURVE 10	
273	-0.0027
360	0.0186
430	0.0479*
479	0.0479
501	0.0745
513	0.1011
543	0.0213
563	-0.0080
583	-0.0080
686	-0.0293
750	-0.0319
CURVE 11	
273	-0.0758
360	0.322
436	0.587
487	0.995
501	1.080
513	1.099
543	1.250
563	1.269
588	1.355
688	1.847
750	2.236

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 2. COEFFICIENT OF THERMAL LINEAR EXPANSION OF ARSENIC As

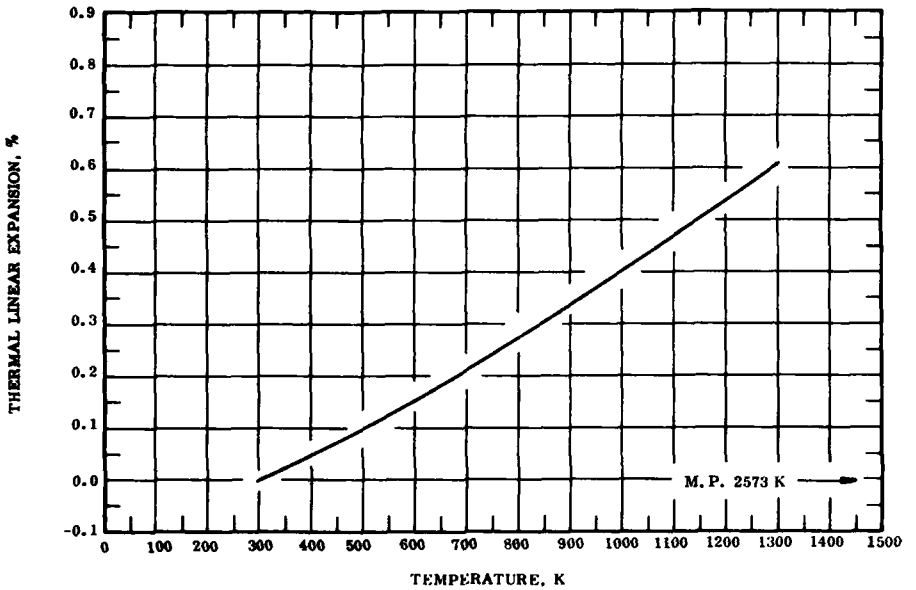
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
2.5	-0.0040
3	-0.0055*
4	-0.0095*
5	-0.016*
6	-0.025*
7	-0.037*
8	-0.052*
10	-0.096
12	-0.165*
14	-0.27*
16	-0.40*
18	-0.55*
20	-0.72
22	-0.89*
24	-1.07*
26	-1.24*
28	-1.40*
30	-1.56
57	-1.80
65	-1.48
75	-1.00
85	-0.60
283	2.60
CURVE 2*,‡	
2.5	-0.0050
3	-0.0065
4	-0.011
5	-0.018
6	-0.029
7	-0.042
8	-0.060
10	-0.114
12	-0.200
14	-0.32
16	-0.48
18	-0.67
20	-0.87
22	-1.10
24	-1.32
26	-1.54
28	-1.75
30	-1.92
57	-2.50
65	-2.20
CURVE 2 (cont.)*,‡	
75	-1.74
85	-1.30
283	1.42
CURVE 3‡	
2.5	0.020*
3	0.032*
4	0.064*
5	0.110*
6	0.180*
7	0.27*
8	0.40*
10	0.75
12	1.33*
14	2.25*
16	3.40*
18	4.70*
20	6.20
22	7.90*
24	9.70*
26	11.40*
28	13.10*
30	14.69
57	29.20
65	31.40
75	33.20
85	34.20
283	41.00
CURVE 4‡	
2.5	-0.0051*
3	-0.0067
4	-0.0114*
5	-0.0186*
6	-0.030*
7	-0.044*
8	-0.062*
10	-0.118*
12	-0.207*
14	-0.33*
16	-0.50
18	-0.69*
20	-0.90*
22	-1.14*
CURVE 4 (cont.)‡	
24	-1.37
26	-1.60*
28	-1.82*
30	-2.00*
57	-2.66
65	-2.37
75	-1.91
85	-1.48
283	1.22

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 3R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF BORON B



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	4.7
400	0.052	5.1
500	0.104	5.4
600	0.159	5.6
700	0.217	5.9
800	0.278	6.2
900	0.340	6.4
1000	0.405	6.6
1100	0.472	6.8
1200	0.541	6.9
1300	0.611	7.1

REMARKS

The recommended values are considered accurate to within ± 5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.123 + 3.672 \times 10^{-4} T + 1.921 \times 10^{-7} T^2 - 3.088 \times 10^{-11} T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ± 5%.

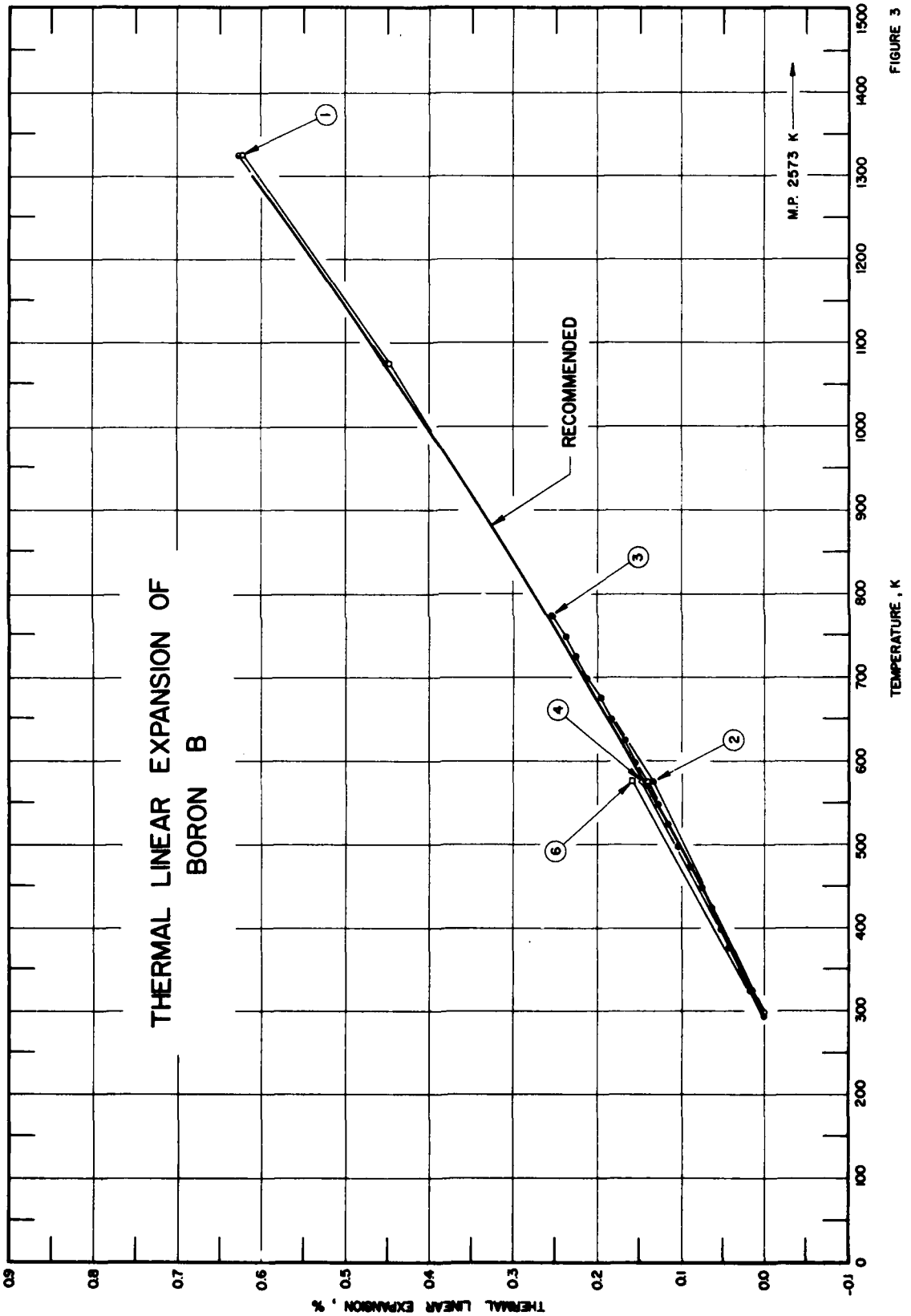

THERMAL LINEAR EXPANSION OF
BORON B
RECOMMENDED
M.P. 2573 K
1
2
3
4
6
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 3

SPECIFICATION TABLE 3. THERMAL LINEAR EXPANSION OF BORON B

Cur. No.	Ref. No.	Author(s)	Year	Metnod Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	354	Speerschneider, C.J. and Sartell, J.A.	1964	L	298-1323		Single crystal, β-rhombohedral, rod specimen; obtained from Texaco Experiment, Inc.; grown by electron beam floating zone procedure; expansion measured in <111> direction.
2	354	Speerschneider, C.J. and Sartell, J.A.	1964	L	298-1323		Polycrystalline specimen.
3	578	Salibekov, S.E., Portnoi, K.I., and Chubarov, V.M.	1971	L	293-773		Dial scale division 1 μ specimens were plates 30 x 4 x 3 mm and were heated in argon atm at 3 deg/min accuracy ± 5%; specimen was plait of boron fibers placed in quartz tube and drawn together by metal thread in several places.
4	579	Witucki, M.	1967	L	323, 573		Specimen sample: 3 in. in length, 11 in. filament length, filament temperature observed optically by using a Micro-Optical Pyrometer when max. filament temperature reached 1030 C true temperature the dial gage was photographed; Filament Lot A, prepared using a multiple step deposition, process; reaction time 200 sec, max. deposition temperature 1990 F, nominal diameter 4.8 mils; Filament not straight, splitting observed, average 2 values (estimated accuracy ± 0.06).
5*	579	Witucki, M.	1967	L	323, 573		Filament Lot A(b); the above specimen except split filament with core removed by etching.
6	579	Witucki, M.	1967	L	323, 573		Filament Lot E; reaction time 360 sec maximum deposition temperature 1600 F nominal diameter 1.2 mils, broken when received, filament not straight.
7*	579	Witucki, M.	1967	L	323, 573		Filament Lot R; reaction time 40 sec, max. deposition temperature 2300°, nominal diameter 2.8 mils, broken when received, filament not straight, splitting observed.
8*	579	Witucki, M.	1967	L	323, 573		Filament Lot T; reaction time 360 sec, max. deposition temperature 2300°, nominal diameter 5.5 mils, broken when received, filament not straight, filament can be fractured to produce well defined extended steps at the fracture ends.

* Not shown in figure.

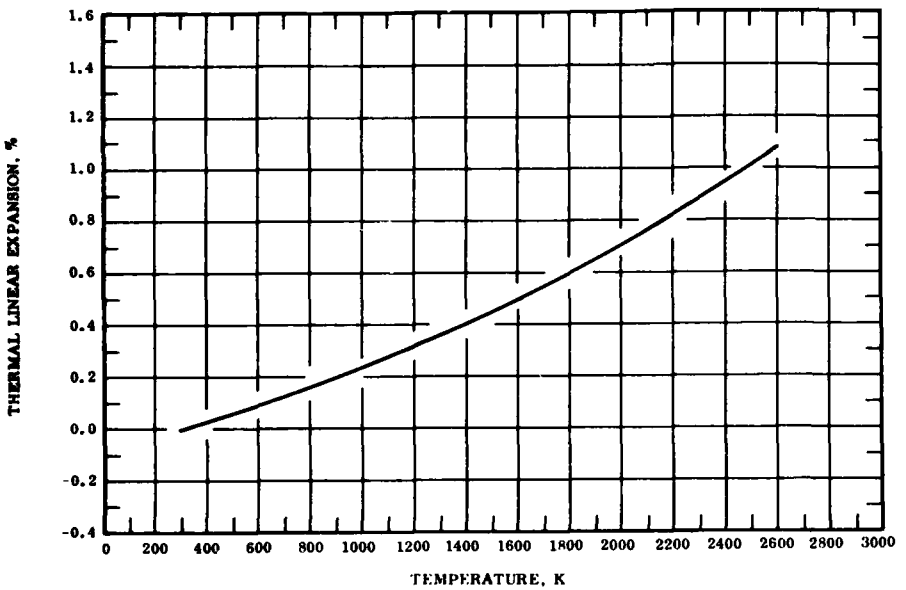
DATA TABLE 3. THERMAL LINEAR EXPANSION OF BORON B

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.003
573	0.140
1073	0.450
1323	0.623
CURVE 2	
298	0.002*
573	0.134
1073	0.454
1323	0.629
CURVE 3	
293	0.000
298	0.005*
323	0.017
348	0.028
373	0.042
398	0.052
423	0.063
448	0.075
473	0.090
498	0.103
523	0.116
548	0.128
573	0.142
598	0.155
623	0.168
648	0.182
673	0.197
698	0.212
723	0.227
748	0.239
773	0.254
CURVE 4	
323	0.016
573	0.147
CURVE 5*	
323	0.016
573	0.148
CURVE 6	
323	0.017
573	0.159
CURVE 7*	
323	0.016
573	0.149
CURVE 8*	
323	0.017
573	0.158

* Not shown in figure.

FIGURE AND TABLE NO. 4R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF GLASSY CARBON C



RECOMMENDED VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

T	$\Delta L/L_0$	α
293	0.000	3.1
400	0.034	3.2
600	0.099	3.4
800	0.168	3.6
1000	0.242	3.8
1200	0.320	4.1
1400	0.405	4.4
1600	0.496	4.8
1800	0.595	5.2
2000	0.703	5.6
2200	0.819	6.1
2400	0.946	6.6
2600	1.084	7.2

REMARKS

The recommended values are based on the data for the heat-treated sample (curve 1) and are considered accurate to within ± 5%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.089 + 3.015 \times 10^{-4} T + 1.286 \times 10^{-8} T^2 + 1.724 \times 10^{-11} T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ± 5%.

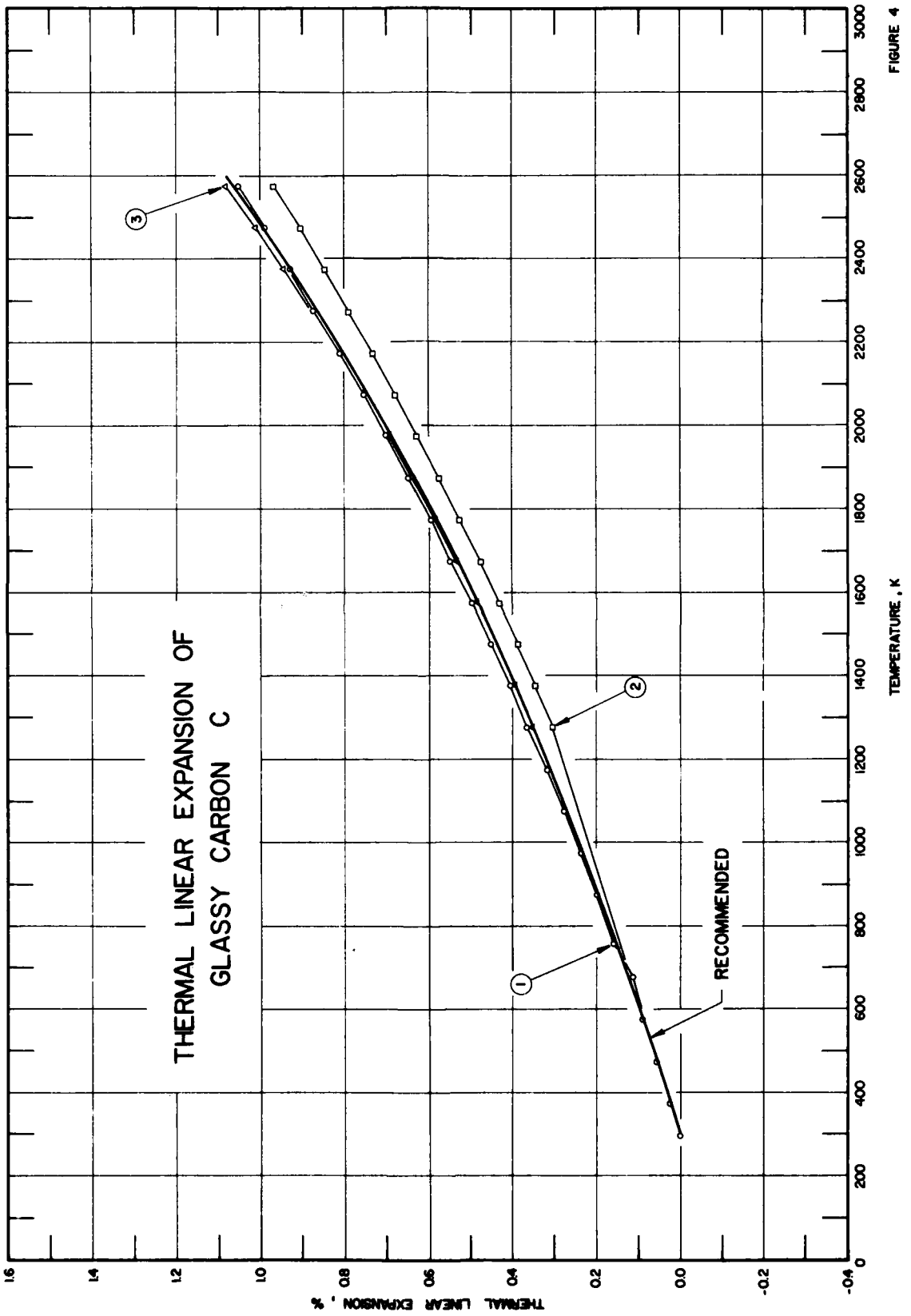

THERMAL LINEAR EXPANSION OF
GLASSY CARBON C
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED
1
2
3
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000

FIGURE 4

SPECIFICATION TABLE 4. THERMAL LINEAR EXPANSION OF GLASSY CARBON C

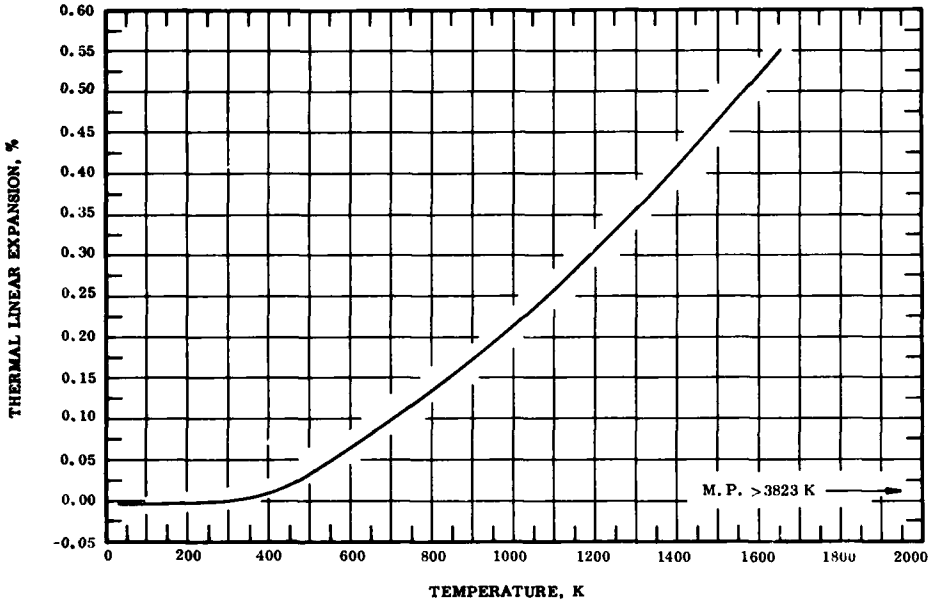
Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	534, 580	Gaal, P.S.	1972	T	296-2573	GC-20	Plate stock specimen 1/8 in. thick; manufactured by Tokai Electrode Manufacturing Co., Ltd., Tokyo, Japan; heat treated; extremely hard and brittle, exhibiting concoidal fractures typical of glass; average data reported of 22 tests; zero-point correction of 0.0008% determined by graphical extrapolation.
2	534, 580	Gaal, P.S.	1972	T	296-2573	GC-20	Similar to the above specimen; tube stock specimen 0.375 in. diameter; not annealed; average data reported on two specimens in 5 tests each; zero-point correction of 0.0008% determined by graphical extrapolation.
3	534, 580	Gaal, P.S.	1972	T	296-2573	GC-30	Similar to the above specimen; tube stock specimen 0.375 in. diameter; not annealed; average data reported on two specimens in 5 tests each; zero-point correction of 0.0011% determined by graphical extrapolation.

DATA TABLE 4. THERMAL LINEAR EXPANSION OF GLASSY CARBON C

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 2 (cont.)		CURVE 3 (cont.)	
296	0.000	2073	0.758	2073	0.680	2173	0.817
373	0.024	2173	0.813	2173	0.734	2273	0.879
473	0.056	2273	0.879	2273	0.791	2373	0.944
573	0.089	2373	0.931	2373	0.849	2473	1.012
673	0.123	2473	0.991	2473	0.909	2573	1.082
773	0.159	2573	1.053	2573	0.970		
873	0.197						
973	0.236	CURVE 2		CURVE 3			
1073	0.276						
1173	0.318	296	0.000	296	0.001		
1273	0.361	1273	0.305	1273	0.351		
1373	0.405	1373	0.346	1373	0.395		
1473	0.451	1473	0.388	1573	0.488		
1573	0.499	1573	0.432	1673	0.537		
1673	0.548	1673	0.478	1773	0.589		
1773	0.598	1773	0.526	1873	0.643		
1873	0.650	1873	0.576	1973	0.698		
1973	0.703	1973	0.627	2073	0.756		

FIGURE AND TABLE NO. 5R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF DIAMOND C



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
25	-0.011	-0.1
50	-0.012	-0.06
100	-0.012	0.05
150	-0.011	0.2
200	-0.009	0.4
250	-0.005	0.7
293	0.000	1.0
350	0.008	1.5
400	0.016	1.8
500	0.037	2.3
600	0.062	2.8
700	0.093	3.2
800	0.127	3.7
900	0.166	4.0
1000	0.208	4.4
1100	0.253	4.7
1200	0.302	5.0
1300	0.352	5.2
1400	0.406	5.4
1500	0.461	5.6
1600	0.519	5.8
1650	0.548	5.8

REMARKS

The recommended values are based on the data for pure samples and are considered accurate to within ± 5%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.010 - 5.911 \times 10^{-5} T + 3.320 \times 10^{-7} T^2 - 5.544 \times 10^{-11} T^3$$

The tabulated values for the coefficient of thermal expansion are derived from the experimental data (curves 4, 9 and 11) and are considered accurate to about ± 7%.

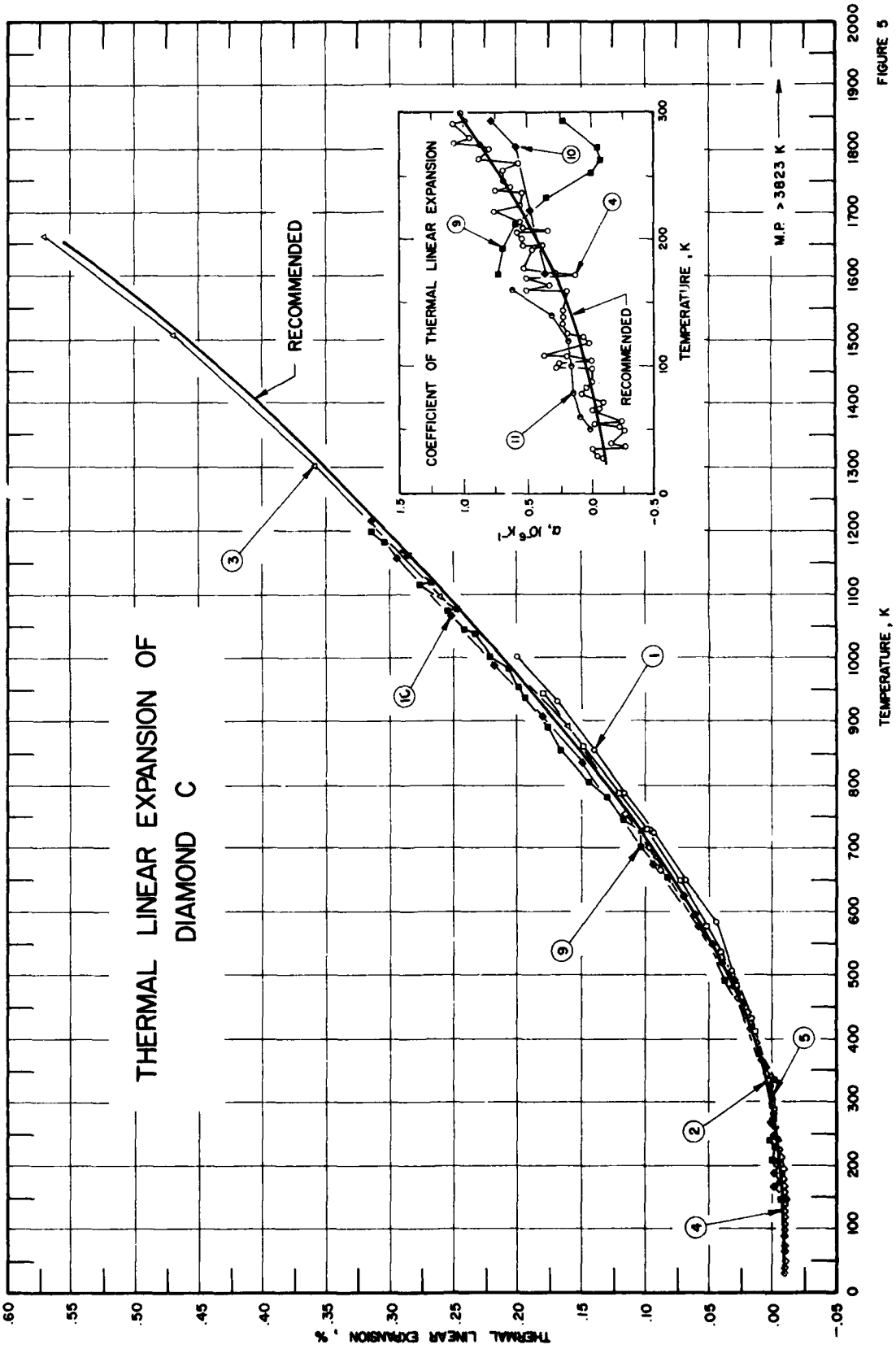

THERMAL LINEAR EXPANSION OF DIAMOND C
RECOMMENDED
M.P. >3823 K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
α, 10⁻⁶ K⁻¹
TEMPERATURE, K

FIGURE 5

SPECIFICATION TABLE 5. THERMAL LINEAR EXPANSION OF DIAMOND C

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	163	Skinner, B.J.	1957	X	294-1002		Commercial grade diamond dust; specimen about 0.2 mm, grain size ≤10 μ; unit cell edge expansion measured; reported unit cell edge a_0 at 294.7 K and 1 atmosphere is 3.56679 Å; 3.56678 Å at 293.2 K determined by graphical extrapolation.
2	163	Skinner, B.J.	1957	X	289-944		Macroscopic single crystal specimen from South West Africa; spotty distribution of impurity content; unit cell edge expansion measured; unit cell edge reported at 289.9 K is 3.56683 Å; 3.56684 Å at 293.2 K determined by graphical interpolation.
3	10	Mauer, F.A. and Bolz, L.N.	1955	X	273-1663		Powder specimen; obtained from Elgin National Watch Co.; No. 1 grade, 0-2 μ; pressed into alumina holder, mounted in Molybdenum furnace and heated in helium atmosphere; 331 and 220 lines used to align specimen and 331 line used for expansion measured; lattice parameter reported at 273.2 K is 3.5672 Å; zero-point correction of -0.002% determined by graphical interpolation.
4	359	Novikova, S.I.	1961	L	28-850		Data given compilation of results of 14 runs on 2 diamond specimens; one obtained from Inst. of Physics Problems of Academy of Sciences, USSR; other obtained from Crystallography Inst.; coefficient of thermal linear expansion also reported.
5	360	Straumanis, M.E. and Aka, E.Z.	1951	X	283-323	White Boart	Specimen obtained from Belgian Congo; stone crushed in steel mortar and treated with hot HCl to remove iron; selved; data of three samples averaged by authors; lattice parameter reported at 293.2 K is 3.55955 kX (or 3.56667 Å).
6*	360	Straumanis, M.E. and Aka, E.Z.	1951	X	283-323	Gray Boart	Similar to the above specimen; lattice parameter reported at 293.2 K is 3.55961 kX (or 3.56673 Å).
7*	360	Straumanis, M.E. and Aka, E.Z.	1951	X	283-323	No. 1	Gem quality stone; similar to the above specimen; lattice parameter reported at 293.2 K is 3.55953 kX (or 3.56665 Å).
8*	360	Straumanis, M.E. and Aka, E.Z.	1951	X	283-323	No. 2	Similar to the above specimen; lattice parameter reported at 293.2 K is 3.55959 kX (or 3.56671 Å).
9	361	Thewlis, J. and Davey, A.R.	1956	X			Industrial quality diamond; held in thin-walled silica capillary of internal diameter 0.5 mm; pure silver powder being mixed with diamond powder for temperature measurement; unit-cell dimension expansion measured; 3.56692 Å reported at 293 K; coefficient of thermal linear expansion also reported.
10	361	Thewlis, J. and Davey, A.R.	1956	X			Gem quality specimen; ground to give crystallites less than 5 μ dia; unit-cell dimension expansion measured; 3.56685 Å reported at 293 K; coefficient of thermal linear expansion also reported.
11*	581	Shah, J.S.	1971	X	40-180		Diamond powder from International Union of Crystallography-Precision Lattice Parameter Project; an original sample of Congo Diamond powder of a crystallite size between band 12 μ used, average of three runs taken; lattice parameter reported as 3.56611 Å at 40 K, lattice parameter not corrected for refraction; lattice parameter 3.56667 Å at 293 K used by TPRC for $\Delta L/L_0$ % calculation; coefficient of thermal linear expansion also reported.

* Not shown in figure.

DATA TABLE 5. THERMAL LINEAR EXPANSION OF DIAMOND C

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
294.7	0.00028
298.2	0.00056
360.4	0.00728
430.4	0.01878
506.3	0.03476
581.7	0.04654
650.9	0.07177
726.2	0.09560
786.5	0.11719
857.7	0.14270
930.9	0.17186
1002.4	0.20270
CURVE 2	
289.9	-0.00028
298.2	0.00028*
335.2	*0.00449*
410.0	0.01598
482.2	0.03055
536.2	0.04345
575.3	0.05326
651.5	0.07569
731.0	0.10177
787.5	0.12167
862.3	0.14999
944.0	0.18251
CURVE 3	
273.2	-0.002
298.2	0.001*
479.2	0.032
685.2	0.093
891.2	0.163
1097.2	0.262
1303.2	0.360
1509.2	0.472
1663.2	0.573
CURVE 4‡	
28	-0.00924
30	-0.00926*
35	-0.00927*
37	-0.00928*
CURVE 4 (cont.)‡	
39	-0.00933
49	-0.00954
52	-0.00961*
54	-0.00963*
56	-0.00966*
65	-0.00977
67	-0.00978*
72	-0.00981
78	-0.00981*
84	-0.00978*
88	-0.00977
98	-0.00977
98	-0.00977*
102	-0.00966*
105	-0.00962
107	-0.00960*
108	-0.00957*
118	*-0.00938*
123	-0.00936*
127	-0.00930
134	-0.00915*
139	-0.00904
143	-0.00894*
158	-0.00862
159	-0.00859*
164	-0.00837*
169	-0.00816
172	-0.00806*
173	-0.00804*
177	-0.00788
192	-0.00713
195	-0.00701*
195	*-0.00701**
200	-0.00674*
205	-0.00645*
207	-0.00636*
209	-0.00627*
213	*-0.00605*
222	-0.00546
227	-0.00513*
237	-0.00458*
238	-0.00452*
241	-0.00431*
246	-0.00398*
255	-0.00336*
260	-0.00304
CURVE 4 (cont.)‡	
264	-0.00275*
272	-0.00208*
275	-0.00183*
276	-0.00173*
281	-0.00122*
292	-0.00010*
293	0.00000*
299	0.00060*
307	0.00142*
309	0.00163*
310	0.00175*
326	0.00399*
332	0.00483*
337	0.00549*
344	0.00652
344	0.00652*
365	0.01069
391	0.01450
394	0.01502*
413	0.01843
440	0.02385
464	0.02920
491	0.03567*
519	0.04264
544	0.04908
572	0.05682*
595	0.06367
624	0.07272
646	0.07988*
677	0.09031
700	0.09825
754	0.11766
CURVE 5	
283	-0.00112
293	0.00000*
303	0.00028
313	0.00252
323	0.00421
CURVE 6*	
283	0.00000
293	0.00000
303	0.00112
CURVE 6 (cont.)*	
313	0.00252
323	0.00561
CURVE 7*	
283	-0.00084
293	0.00000
303	0.00168
313	0.00337
323	0.00506
CURVE 8*	
283	-0.00225
293	0.00000
303	0.00000
313	0.00140
323	0.00337
CURVE 9	
119	-0.0095*
122	-0.0078*
145	-0.0061
170	-0.0100*
208	0.0005
227	-0.0030
238	0.0025
249	0.0011*
264	0.0002*
279	-0.0016*
289	0.0011*
332	*-0.0016*
371	0.0089*
406	0.0145*
490	0.0392
574	0.0585*
655	0.0857
677	0.0925*
699	0.1054
728	0.1059
745	0.1194
780	0.1323
785	0.1284*
806	0.1452
834	0.1513*
CURVE 9 (cont.)	
856	0.1682
858	0.1654*
889	0.1774
933	0.1959
952	0.2018
963	0.2071*
981	0.2071
1000	0.2220
1003	0.2178*
1037	0.2357
1046	0.2436
1075	0.2565
1078	0.2481
1117	0.2800
1120	0.2719
1159	0.2921*
1161	0.2868
1182	0.3050
1198	0.3153
CURVE 10	
139	-0.0100
167	-0.0011
173	-0.0058
186	-0.0028
207	-0.0047
227	-0.0011*
239	-0.0047
246	-0.0019
269	0.0022
357	0.0064
489	*0.0322*
575	0.0608
675	0.0953
833	0.1502
908	0.1830
989	0.2192
1069	0.2537
1160	0.2969
1214	0.3156
CURVE 11*	
40	-0.0157
60	-0.0157
80	-0.0154
100	-0.0151
140	-0.0143
180	-0.0115

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 5. COEFFICIENT OF THERMAL LINEAR EXPANSION OF DIAMOND C

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 4‡	
28	-0.08
30	-0.04
35	0.00
37	-0.26
39	-0.15
49	-0.26
52	-0.22
54	-0.02
56	-0.24
65	0.00
67	-0.07
72	-0.08
78	0.08
84	0.04
88	0.00
98	0.00
98	0.28
102	0.26
105	0.00
107	0.20
108	0.37
118	0.02
123	0.07
127	0.20
134	0.23
139	0.23
143	0.23
158	0.20
159	0.51
164	0.34
169	0.52
172	0.13
173	0.29
177	0.53
192	0.46
195	0.38
195	0.54
200	0.55
205	0.58
207	0.35
209	0.54
213	0.56
222	0.76
227	0.56
237	0.53
238	0.75

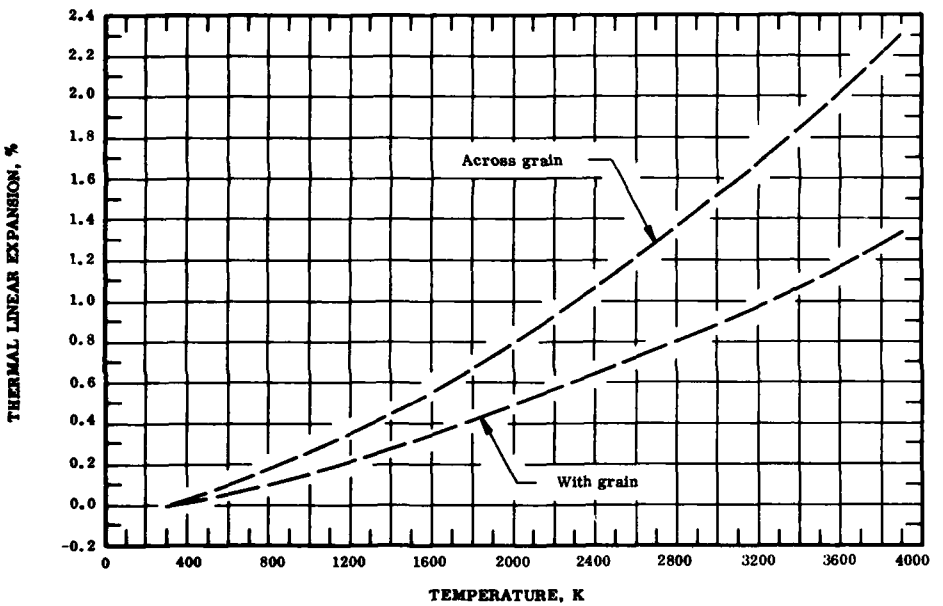
T	α
CURVE 4 (cont.)‡	
241	0.64
246	0.69
255	0.69
260	0.56
264	0.89
272	0.80
275	0.88
276	1.08
281	0.95
292	1.08
293	0.99
299	1.02
307	1.02*
309	1.12*
310	1.27*
326	1.53*
332	1.25*
337	1.42*
344	1.51*
344	1.73*
365	1.65*
391	1.76*
394	1.72*
413	1.87*
440	2.14*
464	2.32*
491	2.47*
519	2.51*
544	2.64*
572	2.89*
595	3.07*
624	3.17*
646	3.34*
677	3.39*
700	3.51*
754	3.68*
CURVE 9	
173	0.73
193	0.69
213	0.58
233	0.36
253	0.00
263	-0.07
273	-0.05

T	α
CURVE 9 (cont.)	
293	0.23
313	0.71*
333	1.14*
353	1.57*
373	1.91*
423	2.41*
473	2.62*
573	2.85*
673	3.28*
773	3.75*
873	3.99*
973	4.11*
1073	4.45*
1173	4.94*
CURVE 10	
173	0.37
223	0.47
273	0.59
293	0.78
323	0.99*
373	1.60*
423	1.91*
473	2.68*
573	3.20*
673	3.39*
773	3.59*
873	4.00*
973	4.30*
1073	4.58*
1173	4.76*
CURVE 11	
50	0.01
60	0.09
80	0.15
100	0.16
120	0.19
140	0.32
160	0.63

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 6R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE 3474 D GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	2.9	0.000	2.2
400	0.032	3.1	0.024	2.3
600	0.099	3.5	0.071	2.4
800	0.174	4.0	0.121	2.6
1000	0.258	4.4	0.175	2.8
1200	0.349	4.8	0.232	2.9
1400	0.448	5.2	0.293	3.1
1600	0.556	5.6	0.357	3.3
1800	0.671	5.9	0.424	3.4
2000	0.793	6.3	0.495	3.6
2200	0.923	6.7	0.568	3.8
2400	1.060	7.0	0.646	4.0
2600	1.204	7.4	0.727	4.1
2800	1.354	7.7	0.811	4.3
3000	1.512	8.0	0.899	4.5
3200	1.676	8.4	0.990	4.6
3400	1.847	8.7	1.085	4.8
3600	2.024	9.0	1.183	5.0
3800	2.207	9.3	1.284	5.2
3900	2.301	9.5	1.336	5.3

REMARKS

The provisional values are considered accurate to within ± 7% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.075 + 2.258 \times 10^{-4}\ T + 1.104 \times 10^{-7}\ T^2 - 3.097 \times 10^{-12}\ T^3$

With grain: $\Delta L/L_0 = -0.060 + 1.946 \times 10^{-4}\ T + 4.093 \times 10^{-8}\ T^2 + 2.592 \times 10^{-13}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 10%.

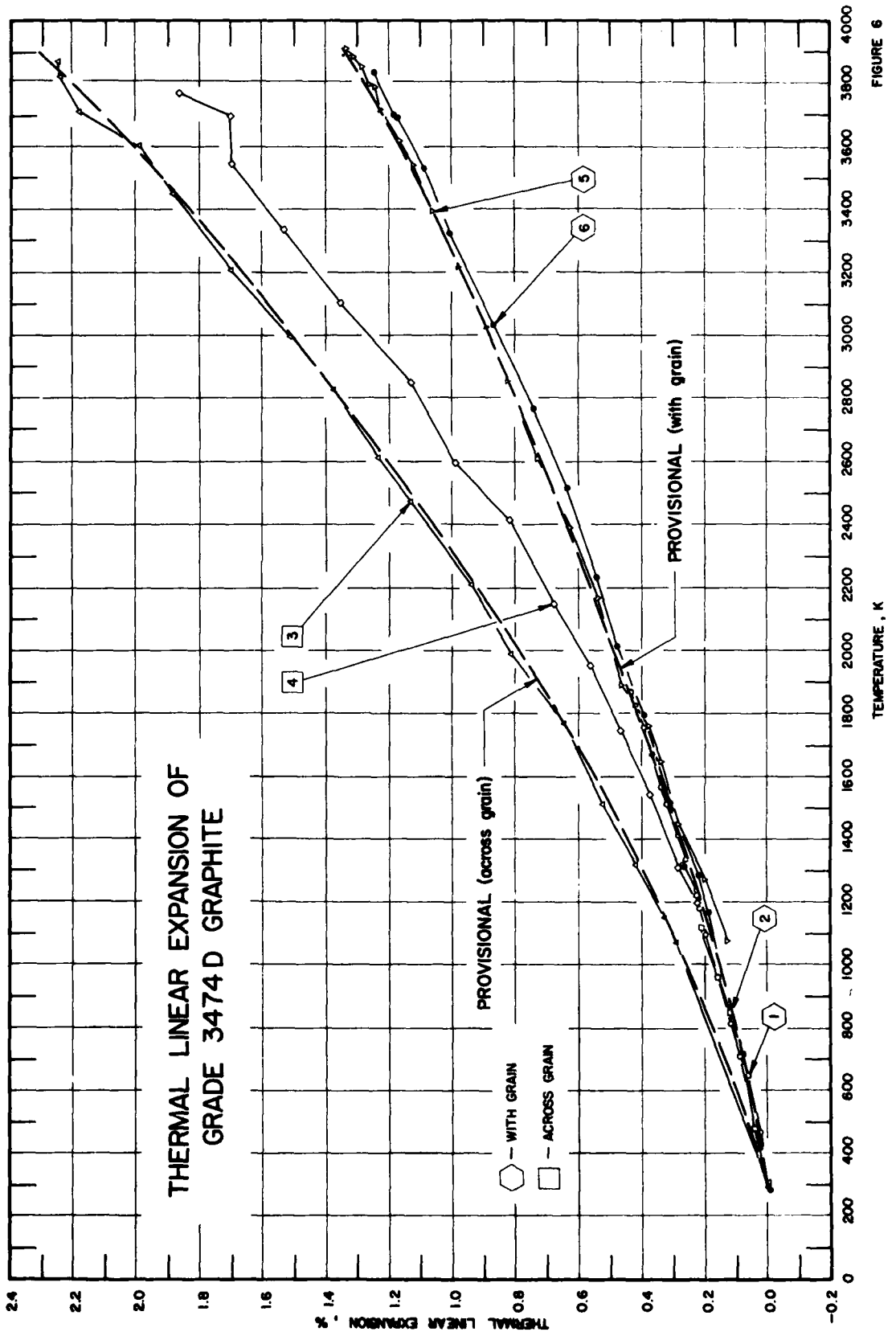

THERMAL LINEAR EXPANSION OF
GRADE 3474 D GRAPHITE
PROVISIONAL (with grain)
PROVISIONAL (across grain)
— WITH GRAIN
— ACROSS GRAIN
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1
2
3
4
5
6

FIGURE 6

SPECIFICATION TABLE 6. THERMAL LINEAR EXPANSION OF GRADE 3474D GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	382	Fieldhouse, I. B., Hedge, J. C., Lang, J. I., Takata, A. N. and Waterman, T. E.	1956	T	297-1861		Rod specimen; data averaged from three separate runs; zero-point correction of 0.001% determined by graphical extrapolation.
2	382	Fieldhouse, I. B., et al.	1956	T	1158-297		The above specimen; expansion measured with decreasing temperature; zero-point correction of 0.001% determined by graphical extrapolation.
3	383	Rasor, N. S. and McClelland, J. D.	1957	T	302-3864		Specimen obtained from Speer Carbon Co.; extruded; very fine grained; expansion measured perpendicular to extrusion axis; zero-point correction of 0.000% determined by graphical extrapolation.
4	383	Rasor, N. S. and McClelland, J. D.	1957	T	3768-1191		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.300% determined by graphical extrapolation.
5	383	Rasor, N. S. and McClelland, J. D.	1957	T	1074-3915		The above specimen; expansion measured parallel to extrusion axis with increasing temperature; zero-point correction of 0.000% determined by graphical extrapolation.
6	383	Rasor, N. S. and McClelland, J. D.	1957	T	3829-282		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.013% determined by graphical interpolation.

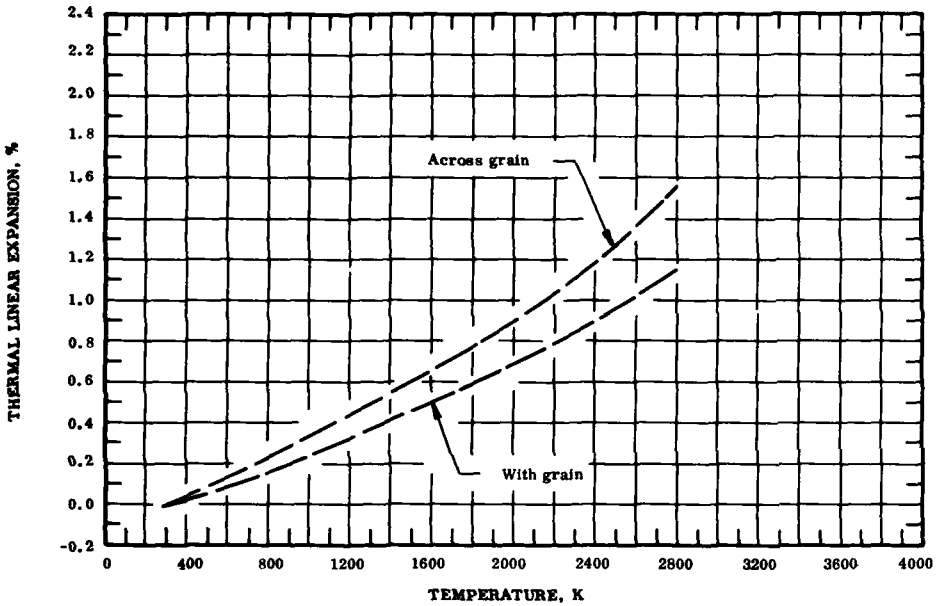
DATA TABLE 6. THERMAL LINEAR EXPANSION OF GRADE 3474D GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
297	0.001
464	0.031
644	0.069
711	0.090
814	0.121
1096	0.200
1178	0.225
1220	0.233
1239	0.233
1319	0.270
1320	0.274
1339	0.268
1408	0.290
1516	0.324
1562	0.341
1669	0.379
1755	0.406
1823	0.432
1861	0.443
CURVE 2	
1158	0.220
958	0.162
841	0.125
711	0.089
478	0.047
297	0.001*
CURVE 3	
302	0.000
1066	0.298
1144	0.333
1321	0.425
1514	0.532
1762	0.654
1988	0.822
2209	0.944
2471	1.138
2611	1.243
CURVE 3 (cont.)	
2821	1.379
2997	1.516
3207	1.703
3448	1.885
3606	1.996
3714	2.182
3817	2.246
3864	2.248
CURVE 4	
3768	1.870
3700	1.706
3543	1.700
3339	1.536
3104	1.359
2846	1.135
2596	0.998
2406	0.827
CURVE 4 (cont.)	
2148	0.683
1947	0.571
1742	0.474
1541	0.381
1314	0.289
1191	0.230
CURVE 5	
1074	0.138
1274	0.207
1448	0.291
1642	0.346
1760	0.389
1987	0.472
2169	0.547
2388	0.639
2604	0.734
2852	0.831
CURVE 5 (cont.)	
3026	0.898
3215	0.984
3393	1.064
3540	1.125
3621	1.178
3723	1.231
3786	1.246
3791	1.267
3848	1.288
3881	1.313
3898	1.323
3915	1.334
CURVE 6	
3829	1.252
3703	1.195
3696	1.180
3529	1.091
CURVE 6 (cont.)	
3323	1.013
3034	0.873
2764	0.749
2520	0.646
2234	0.549
2017	0.487
1793	0.405
1518	0.319
1284	0.231
1162	0.197
282	-0.002

* Not shown in figure.

FIGURE AND TABLE NO. 7R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE 3499 GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	5.0	0.000	3.2
400	0.056	5.0	0.035	3.3
600	0.157	5.0	0.104	3.5
800	0.255	5.1	0.176	3.7
1000	0.355	5.1	0.252	3.9
1200	0.454	5.1	0.332	4.1
1400	0.555	5.3	0.416	4.3
1600	0.664	5.5	0.505	4.5
1800	0.776	6.0	0.598	4.8
2000	0.906	6.6	0.697	5.0
2200	1.037	7.4	0.800	5.3
2400	1.196	8.2	0.909	5.6
2600	1.367	9.2	1.024	5.9
2800	1.575	10.3	1.144	6.2

REMARKS

The provisional values are considered accurate to within ± 7% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.166 + 6.044 \times 10^{-4} T - 1.395 \times 10^{-7} T^2 + 5.149 \times 10^{-11} T^3$

With grain: $\Delta L/L_0 = -0.092 + 3.045 \times 10^{-4} T + 3.512 \times 10^{-8} T^2 + 4.948 \times 10^{-12} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 10%.

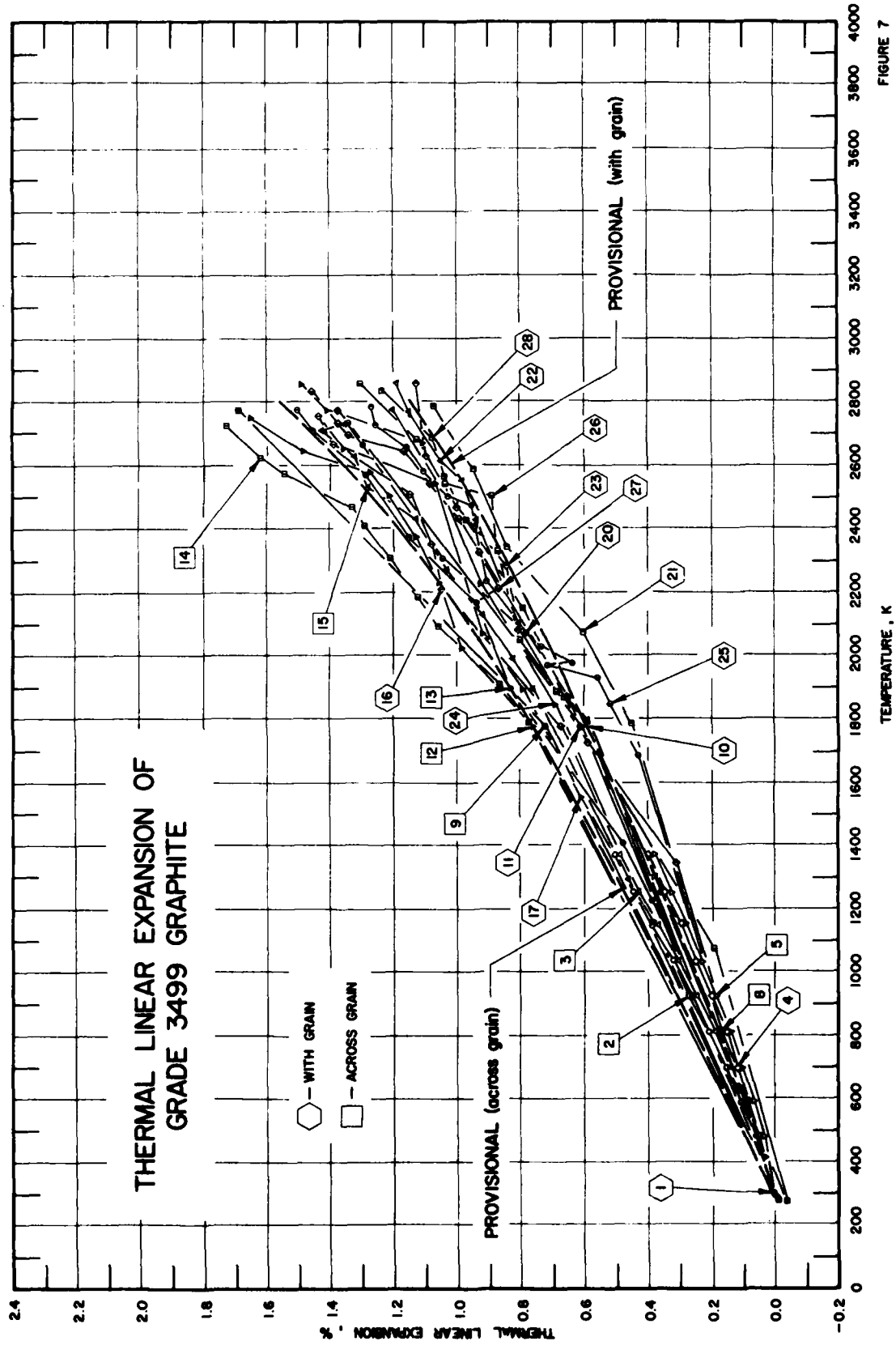

THERMAL LINEAR EXPANSION OF
GRADE 3499 GRAPHITE
WITH GRAIN
ACROSS GRAIN
PROVISIONAL (with grain)
PROVISIONAL (across grain)
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000

FIGURE 7

SPECIFICATION TABLE 7. THERMAL LINEAR EXPANSION OF GRADE 3499 GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	368	Allen, R.D.	1959	L	300-1366	Block No. 0104	Specimen obtained from Speer Carbon Co.; dimensions 0.25 in. diameter and 2 in. long; maximum filler particle size 0.005 in.; petroleum coke mixed with coal tar pitch, impregnated with coal tar pitch, molded and graphitized at above 2533 K; heated in atmosphere of helium with heating rate of 555 K per hr; soaked 0.5 hr at 1366 K; expansion measured parallel to the grain direction.
2	368	Allen, R.D.	1959	L	300-1366	Block No. 0104	The above specimen except expansion measured perpendicular to the grain direction.
3	368	Allen, R.D.	1959	L	300-1366	Block No. 0104	The above specimen.
4	368	Allen, R.D.	1959	L	300-1366	Block No. 0105	Similar to the above specimen except expansion measured parallel to the grain direction.
5	368	Allen, R.D.	1959	L	300-1366	Block No. 0105	The above specimen except expansion measured perpendicular to the grain direction.
6*	368	Allen, R.D.	1959	L	300-1366	Block No. 0105	The above specimen.
7*	368	Allen, R.D.	1959	L	300-1366	Block No. 0107	Similar to the above specimen except expansion measured parallel to the grain direction.
8	368	Allen, R.D.	1959	L	300-1366	Block No. 0107	The above specimen except expansion measured perpendicular to the grain direction.
9	372	Bradstreet, S.W., Atlas, L.M., Bortz, S.A., Lund, H.H., and Nakamura, H.H.	1960	L	273-2773		Specimen obtained from Speer Carbon Co.; non-impregnated; molded; expansion measured across grain.
10	372	Bradstreet, S.W., et al.	1960	L	273-2773		The above specimen except expansion measured along the grain.
11	372	Bradstreet, S.W., et al.	1960	L	273-2773		The above specimen except expansion measured along the grain.
12	372	Bradstreet, S.W., et al.	1960	L	293-2777	A2	Specimen obtained from Speer Carbon Co.; original length 2 in.; expansion measured perpendicular to the basal plane.
13	372	Bradstreet, S.W., et al.	1960	L	2777-273	A2	The above specimen; expansion measured with decreasing temperature.
14	372	Bradstreet, S.W., et al.	1960	L	293-2728	A3	Specimen obtained from Speer Carbon Co.; original length 2 in.; measured perpendicular to the basal plane with the increasing temperature.
15	372	Bradstreet, S.W., et al.	1960	L	2728-273	A3	The above specimen; expansion measured with decreasing temperature.
16	372	Bradstreet, S.W., et al.	1960	L	293-2759	A5	Specimen obtained from Speer Carbon Co.; original length 2 in.; expansion measured parallel to the basal plane.
17	372	Bradstreet, S.W., et al.	1960	L	2759-413	A5	The above specimen; expansion measured with decreasing temperature.
18*	372	Bradstreet, S.W., et al.	1960	L	413-2759	W_1-4	Specimen obtained from Speer Carbon Co.; original length 2 in.; expansion measured parallel to the basal plane.
19*	372	Bradstreet, S.W., et al.	1960	L	2759-413	W_1-4	The above specimen; expansion measured with decreasing temperature.
20	372	Bradstreet, S.W., et al.	1960	L	293-2783	W_1-5	Specimen obtained from Speer Carbon Co.; original length 2 in.; expansion measured parallel to the basal plane.
21	372	Bradstreet, S.W., et al.	1960	L	2783-273	W_1-5	The above specimen; expansion measured with decreasing temperature.
22	372	Bradstreet, S.W., et al.	1960	L	293-2859	W_1-6	Specimen obtained from Speer Carbon Co.; original length 2 in.; expansion measured parallel to the basal plane.

* Not shown in figure.

SPECIFICATION TABLE 7. THERMAL LINEAR EXPANSION OF GRADE 3499 GRAPHITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
23	372	Bradstreet, S.W., et al.	1960	L	2859-273	W_1-6	The above specimen; expansion measured with decreasing temperature.
24	372	Bradstreet, S.W., et al.	1960	L	293-2858	W_2-1	Specimen obtained from Speer Carbon Co.; original length 2 in.; expansion measured parallel to the basal plane.
25	372	Bradstreet, S.W., et al.	1960	L	293-2738	W_2-2	Specimen obtained from Speer Carbon Co.; original length 2 in.; expansion measured parallel to the basal plane.
26	372	Bradstreet, S.W., et al.	1960	L	2858-273	W_2-2	The above specimen; expansion measured with decreasing temperature.
27	372	Bradstreet, S.W., et al.	1960	L	293-2833	W_2-3	Specimen obtained from Speer Carbon Co.; original length 2 in.; expansion measured parallel to the basal plane.
28	372	Bradstreet, S.W., et al.	1960	L	2833-273	W_2-3	The above specimen; expansion measured with decreasing temperature.

DATA TABLE 7. THERMAL LINEAR EXPANSION OF GRADE 3499 GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
300	0.002
477	0.061
588	0.110
700	0.159
810	0.212
922	0.268
1033	0.326
1144	0.391
1255	0.452
1366	0.510
CURVE 2	
300	0.002*
477	0.056
588	0.102
700	0.157*
810	0.214*
922	0.278
1033	0.333*
1144	0.394*
1255	0.452*
1366	0.512*
CURVE 3	
300	0.001*
477	0.049*
588	0.093
700	0.141
810	0.194
922	0.251
1033	0.312
1144	0.371
1255	0.435
1366	0.495
CURVE 4	
300	0.002*
477	0.053*
588	0.086*
700	0.124
810	0.165
922	0.208
1033	0.256
1144	0.306
1255	0.355
1366	0.406
CURVE 5	
300	0.001*
477	0.039
588	0.072
700	0.110
810	0.147
922	0.194
1033	0.237
1144	0.286
1255	0.336
1366	0.383
CURVE 6*	
300	0.002
477	0.042
588	0.079
700	0.119
810	0.164
922	0.209
1033	0.254
1144	0.306
1255	0.362
1366	0.412
CURVE 7*	
300	0.002
477	0.044
588	0.076
700	0.114
810	0.156
922	0.200
1033	0.246
1144	0.297
1255	0.348
1366	0.402
CURVE 8	
300	0.002*
477	0.048*
588	0.083*
700	0.124*
810	0.171
922	0.209*
1033	0.260*
1144	0.309*
1255	0.362
1366	0.412*
CURVE 9	
273	-0.010
1773	0.728
2773	1.691
CURVE 10	
273	-0.016*
1773	0.599
2773	1.203
CURVE 11	
273	-0.008*
1773	0.610
2773	1.377
CURVE 12	
293	0.000
1775	0.764
2022	0.986
2238	1.062
2376	1.134
2503	1.219
2573	1.275
2641	1.486
2752	1.656
2777	1.684*
CURVE 13	
2777	1.509
2713	1.451
2568	1.288
2373	1.156
2168	0.941
1898	0.826
1403	0.481
1228	0.391
273	-0.011*
CURVE 14	
293	0.000*
1785	0.774
1908	0.866
2098	1.064
2183	1.132
2315	1.211
2405	1.291
1468	1.336
2573	1.549
2623	1.621
2728	1.730
CURVE 15	
2728	1.355
2715	1.429
2624	1.329
2533	1.281
2428	1.138
2273	1.036
2133	0.925
1988	0.830
1898	0.761
1298	0.466
273	-0.005*
CURVE 16	
293	0.000*
1773	0.679
2208	1.054
2356	1.086
2509	1.153
2663	1.396
2759	1.439
2759	1.439*
2653	1.360
2543	1.071
2063	0.924
1893	0.796
1553	0.615
1153	0.391
413	0.036
CURVE 18*	
413	0.036
1153	0.391
1553	0.615
1893	0.796
2063	0.924
2543	1.071
2653	1.360
2759	1.439
CURVE 19*	
2759	1.439
2653	1.360
2543	1.071
2063	0.924
1893	0.796
1553	0.615
1153	0.391
413	0.036
CURVE 20	
293	0.000*
1773	0.618*
1863	0.655
2073	0.782
2233	0.913
2403	0.944
2473	0.958
2503	1.033
2578	1.114
2658	1.163
2728	1.258
2783	1.270
CURVE 21	
2783	1.080
2583	0.953
2343	0.845
2075	0.608
1783	0.457
273	-0.012*
CURVE 22	
293	0.000*
1798	0.593
2105	0.810
2428	0.945
2556	0.990
2618	1.060
2768	1.158
2859	1.196
CURVE 23	
2859	1.136
2628	1.107
2468	1.003
2283	0.845
2080	0.808
1726	0.595
1343	0.320
273	-0.017*
CURVE 24	
293	0.000*
1843	0.695
2223	0.928
2671	1.118
2773	1.410
2858	1.493
CURVE 25	
293	0.000*
1683	0.438
1844	0.523
1928	0.565
1971	0.723
1976	0.643

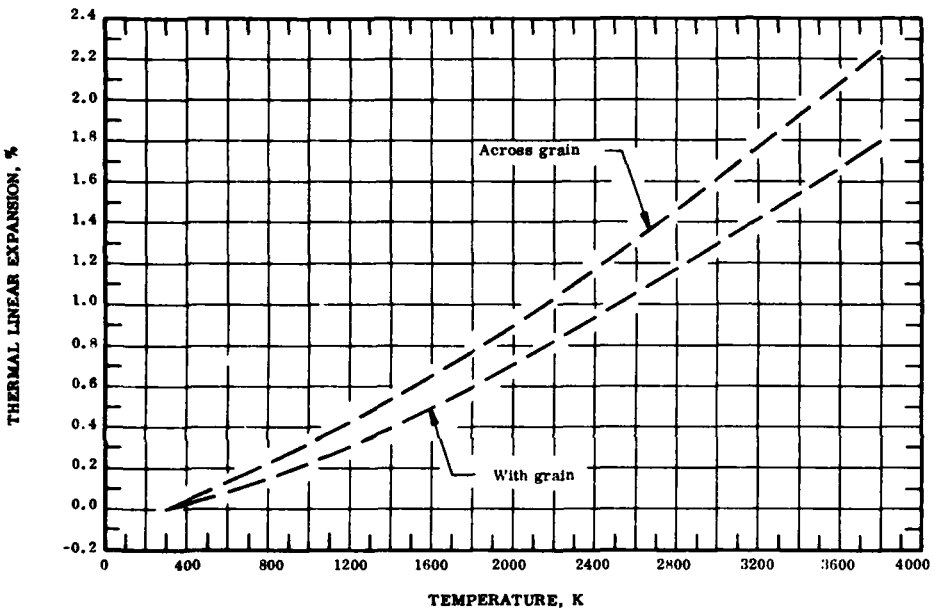
* Not shown in figure.

DATA TABLE 7. THERMAL LINEAR EXPANSION OF GRADE 3499 GRAPHITE (continued)

T	$\Delta L/L_0$
CURVE 25 (cont.)	
2028	0.743
2317	1.048
2663	1.298
2738	1.348
CURVE 26	
2858	1.303
2681	1.130
2543	1.040
2503	0.894
2336	0.878
2048	0.805
1883	0.693
1073	0.198
273	-0.035
CURVE 27	
293	0.000*
1773	0.608*
2073	0.777*
2163	0.945*
2210	0.871
2328	0.935
2429	0.995
2543	1.095
2643	1.168
2698	1.343
2736	1.372
2833	1.460
CURVE 28	
2833	1.240
2683	1.084
2563	1.044
2423	0.972
2153	0.796
1861	0.663
1303	0.383
273	0.025*

* Not shown in figure.

FIGURE AND TABLE NO. 8R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE 7087 GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	3.9	0.000	2.4
400	0.042	4.1	0.027	2.6
600	0.127	4.4	0.084	3.1
800	0.219	4.7	0.151	3.6
1000	0.317	5.1	0.226	4.0
1200	0.421	5.4	0.309	4.3
1400	0.531	5.7	0.399	4.7
1600	0.647	5.9	0.496	5.0
1800	0.769	6.2	0.598	5.2
2000	0.896	6.5	0.705	5.5
2200	1.028	6.7	0.817	5.7
2400	1.165	7.0	0.933	5.9
2600	1.306	7.2	1.051	6.0
2800	1.452	7.4	1.172	6.1
3000	1.602	7.6	1.295	6.2
3200	1.756	7.8	1.418	6.2
3400	1.913	8.0	1.542	6.2
3600	2.074	8.1	1.665	6.2
3800	2.238	8.3	1.788	6.2

REMARKS

The provisional values are based on the data for heating cycles (curve 2 for across grain, curves 4 and 6 for with grain). These values are considered accurate to within ± 7% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.106 + 3.340 \times 10^{-4}\ T + 9.347 \times 10^{-6}\ T^2 - 5.013 \times 10^{-12}\ T^3$

With grain: $\Delta L/L_0 = -0.057 + 1.578 \times 10^{-4}\ T + 1.403 \times 10^{-7}\ T^2 - 1.422 \times 10^{-11}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 10%.

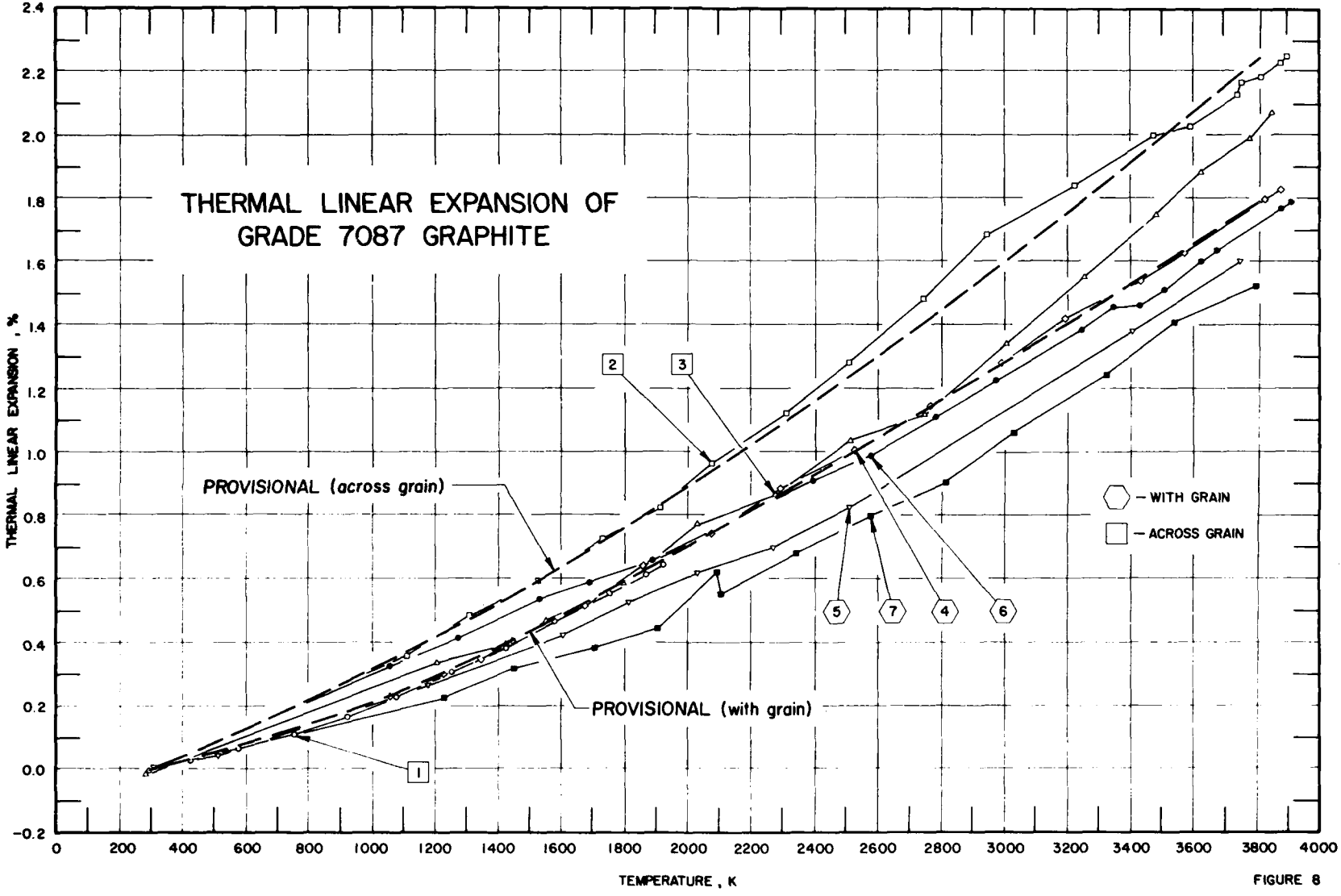

THERMAL LINEAR EXPANSION OF
GRADE 7087 GRAPHITE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
PROVISIONAL (across grain)
PROVISIONAL (with grain)
WITH GRAIN
ACROSS GRAIN
1
2
3
4
5
6
7
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000

FIGURE 8

SPECIFICATION TABLE 8. THERMAL LINEAR EXPANSION OF GRADE 7087 GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	385	Lucks, C.F. and Deem, H.W.	1956	L	293-1922		Specimen obtained from Speer Carbon Co.; 0.375 in. in diameter and 3 in. long; extruded; heated at rate less than 5 F per min; density 0.0618 lb $in.^{-3}$ at 297 K; measured perpendicular to the direction of extrusion.
2	383	Rasor, N.S. and McClelland, J.D.	1957	T	293-3897		Extruded specimen obtained from Speer Carbon Co.; coarse grained with small voids and fissures; expansion measured perpendicular to extrusion axis with increasing temperature; zero-point correction of -0.026%.
3	383	Rasor, N.S. and McClelland, J.D.	1957	T	3841-281		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.130% determined by graphical interpolation.
4	383	Rasor, N.S. and McClelland, J.D.	1957	T	293-3875		The above specimen; expansion measured parallel to extrusion axis with increasing temperature on first thermal cycle.
5	383	Rasor, N.S. and McClelland, J.D.	1957	T	3752-305		The above specimen; expansion measured with decreasing temperature on first thermal cycle; zero-point correction of -0.120% determined by graphical extrapolation.
6	383	Rasor, N.S. and McClelland, J.D.	1957	T	293-3911		The above specimen; expansion measured with increasing temperature on second thermal cycle; zero-point correction of -0.017%.
7	383	Rasor, N.S. and McClelland, J.D.	1957	T	3974-293		The above specimen; expansion measured with decreasing temperature on second thermal cycle; zero-point correction of -0.173%.

DATA TABLE 8. THERMAL LINEAR EXPANSION OF GRADE 7087 GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

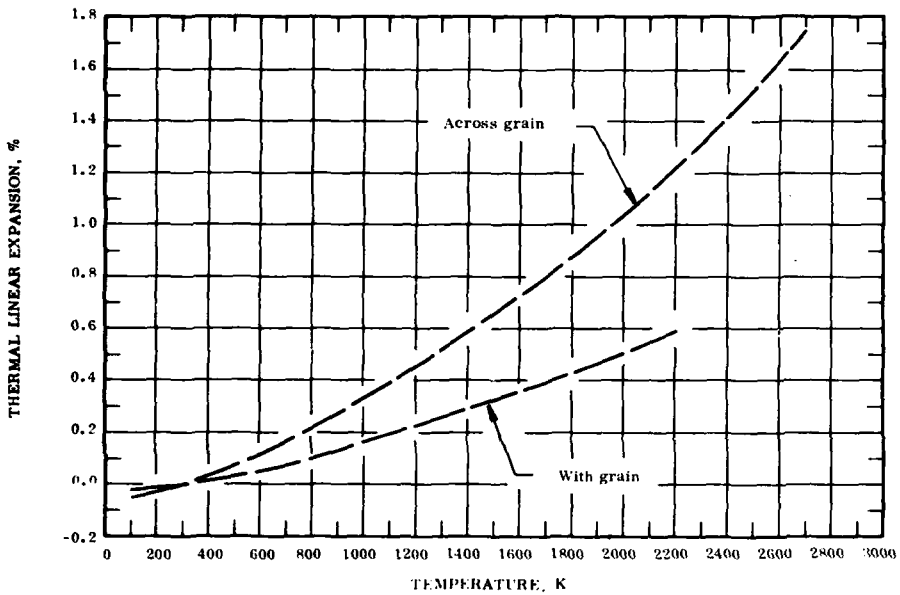
T	$\Delta L/L_0$
CURVE 1	
293	0.000
422	0.032
589	0.070
755	0.115
922	0.172
1089	0.239
1255	0.313
1422	0.391
1589	0.475
1755	0.563
1866	0.623
1922	0.655
CURVE 2	
293	0.000*
1106	0.363
1314	0.493
1529	0.603
1737	0.733
1915	0.838
2088	0.970
2318	1.128
2511	1.293
2747	1.486
2948	1.690
3222	1.848
3479	2.009
3595	2.031
3743	2.135
3758	2.169
3808	2.189
3875	2.232
3897	2.249
CURVE 3	
3841	2.075
3780	1.992
3628	1.886
3483	1.753
3258	1.560
3006	1.345
2747	1.124
2519	1.043

T	$\Delta L/L_0$
CURVE 3 (cont.)	
2279	0.870
2030	0.780
1791	0.593
1558	0.475
1423	0.404
1204	0.343
281	-0.012
CURVE 4	
293	0.000*
1052	0.239
1227	0.309
1345	0.357
1444	0.414
1677	0.522
1858	0.652
2076	0.750
2298	0.890
2529	1.014
2763	1.158
2988	1.287
3194	1.426
3432	1.543
3574	1.635
3822	1.801
3875	1.835
CURVE 5	
3752	1.605
3404	1.381
2514	0.833
2270	0.705
2030	0.629
1816	0.534
1606	0.436
1176	0.276
517	0.046
305	0.012
CURVE 6	
293	0.000*
1055	0.336

T	$\Delta L/L_0$
CURVE 6 (cont.)	
1276	0.422
1537	0.546
1691	0.598
1887	0.669
2395	0.911
2575	0.996
2782	1.111
2987	1.235
3243	1.388
3346	1.464
3426	1.463
3514	1.515
3628	1.607
3672	1.644
3875	1.776
3911	1.798
CURVE 7	
3794	1.528*
3540	1.413
3325	1.251
3033	1.065
2809	0.909
2578	0.808
2341	0.687
2108	0.560
2098	0.635
1902	0.454
1702	0.394
1452	0.326
1229	0.235
293	0.000

* Not shown in figure.

FIGURE AND TABLE NO. 9R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE A GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
100	-0.067	0.8	-0.019	0.1
150	-0.050	1.8	-0.016	0.7
200	-0.033	3.3	-0.011	1.3
250	-0.016	4.1	-0.005	1.7
293	0.000	4.2	0.000	1.9
400	0.041	4.3	0.016	2.0
600	0.125	4.5	0.054	2.2
800	0.220	5.0	0.103	2.7
1000	0.327	5.6	0.160	3.0
1200	0.444	6.2	0.224	3.3
1400	0.574	6.8	0.293	3.6
1600	0.716	7.4	0.366	3.7
1800	0.871	8.1	0.440	3.8
2000	1.040	8.8	0.515	4.0
2200	1.222	9.5	0.589	4.2
2400	1.418	10.2		
2600	1.630	10.9		
2700	1.741	11.3		

REMARKS

The provisional values are considered accurate to within ± 7% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.098 + 2.994 \times 10^{-4} T + 1.156 \times 10^{-7} T^2 + 9.553 \times 10^{-12} T^3$

With grain: $\Delta L/L_0 = -0.024 + 3.186 \times 10^{-5} T + 1.865 \times 10^{-7} T^2 - 3.373 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are derived from the experimental data and are considered accurate to about ± 7%.

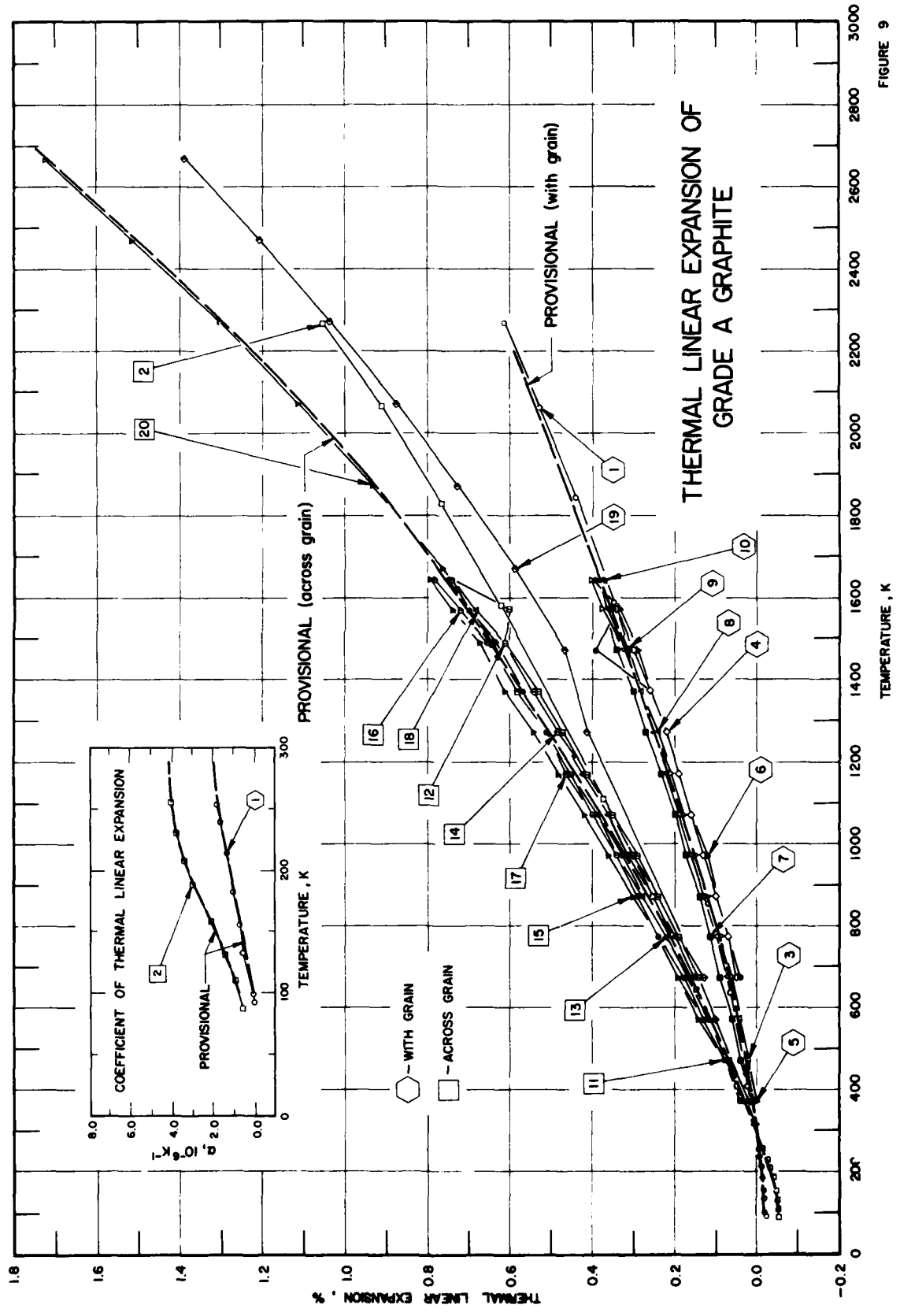

THERMAL LINEAR EXPANSION OF GRADE A GRAPHITE
PROVISIONAL (with grain)
PROVISIONAL (across grain)
WITH GRAIN
ACROSS GRAIN
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
PROVISIONAL
α , 10⁻⁶K⁻¹
TEMPERATURE , K

FIGURE 9

SPECIFICATION TABLE 9. THERMAL LINEAR EXPANSION OF GRADE A GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	356	Mason, I.B. and Knibbs, R.N.	1964	L	91-2270		British reactor grade A graphite; expansion measured parallel to extrusion.
2	356	Mason, I.B. and Knibbs, R.N.	1964	L	87-2269		The above specimen; expansion measured perpendicular to extrusion.
3	164	Burdick, M.D., Zweig, B. and Moreland, R.E.	1954	L	373-1643	Specimen A_1 Test No. 20	Extruded; cut parallel to extrusion direction; right cylinder machined to ~0.375 in. diameter, 2 in. long; reported error ± 0.02%.
4	164	Burdick, M.D., et al.	1954	L	1643-673	Specimen A_1 Test No. 20	The above specimen; expansion measured with decreasing temperature; held at 1643 K for 45 min. before cooling.
5	164	Burdick, M.D., et al.	1954	L	373-1643	Specimen A_2 Test No. 21	Similar to the above specimen; expansion measured with increasing temperature.
6	164	Burdick, M.D., et al.	1954	L	1643-673	Specimen A_2 Test No. 21	The above specimen; expansion measured with decreasing temperature; held at 1643 K for 45 min before cooling.
7	164	Burdick, M.D., et al.	1954	L	373-1643	Specimen X_1 Test No. 18	Similar to the above specimen; expansion measured with increasing temperature.
8	164	Burdick, M.D., et al.	1954	L	1643-673	Specimen X_1 Test No. 18	The above specimen; expansion measured with decreasing temperature; held at 1643 K for 45 min before cooling.
9	164	Burdick, M.D., et al.	1954	L	373-1643	Specimen X_2 Test No. 19	Similar to the above specimen; expansion measured with increasing temperature.
10	164	Burdick, M.D., et al.	1954	L	1643-673	Specimen X_2 Test No. 19	The above specimen; expansion measured with decreasing temperature; held at 1643 K for 45 min before cooling.
11	164	Burdick, M.D., et al.	1954	L	373-1643	Specimen L Test No. 14	Similar to the above specimen; except cut perpendicular to extrusion direction; expansion measured with increasing temperature.
12	164	Burdick, M.D., et al.	1954	L	1643-673	Specimen L Test No. 14	The above specimen; expansion measured with decreasing temperature; held at 1643 K for 45 min before cooling.
13	164	Burdick, M.D., et al.	1954	L	373-1643	Specimen M Test No. 17	Similar to the above specimen; expansion measured with increasing temperature.
14	164	Burdick, M.D., et al.	1954	L	1643-673	Specimen M Test No. 17	The above specimen; expansion measured with decreasing temperature; held at 1643 K for 45 min before cooling.
15	164	Burdick, M.D., et al.	1954	L	373-1643	Specimen U_1 Test No. 15	Similar to the above specimen; expansion measured with increasing temperature.
16	164	Burdick, M.D., et al.	1954	L	1643-673	Specimen U_1 Test No. 15	The above specimen; expansion measured with decreasing temperature; held at 1643 K for 45 min before cooling.
17	164	Burdick, M.D., et al.	1954	L	373-1643	Specimen U_2 Test No. 16	Similar to the above specimen; expansion measured with increasing temperature.
18	164	Burdick, M.D., et al.	1954	L	1643-673	Specimen U_2 Test No. 16	The above specimen; expansion measured with decreasing temperature; held at 1643 K for 45 min before cooling.
19	403	Volk, H.F., Epremian, E. and Criscione, J.M.	1963	L	313-2673		Expansion measured with grain.
20	403	Volk, H.F., et al.	1963	L	313-2673		Expansion measured across grain.

DATA TABLE 9. THERMAL LINEAR EXPANSION OF GRADE A GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$]

T	$\Delta L/L_0$
CURVE 1‡	
91	-0.022
99	-0.021
133	-0.020
154	-0.019
183	-0.017
213	-0.013
239	-0.009
253	-0.007
410	0.021
639	0.066
859	0.119
1110	0.191
1588	0.345
1842	0.440
2062	0.529
2270	0.614
CURVE 2‡	
87	-0.057
110	-0.055
131	-0.053
157	-0.048
187	-0.041
207	-0.034
230	-0.026
255	-0.016
408	0.048
641	0.146
876	0.253
1112	0.371
1581	0.620
1831	0.762
2066	0.911
2269	1.052
CURVE 3	
373	0.01
473	0.02
573	0.04
673	0.07
773	0.10
873	0.13
973	0.16
1073	0.19
CURVE 3 (cont.)	
1173	0.22
1273	0.25
1373	0.28
1473	0.32
1573	0.36
1643	0.38
CURVE 4	
1643	0.38*
1573	0.34
1473	0.30
1373	0.26
1273	0.22
1173	0.19
1073	0.16
973	0.13
873	0.10
773	0.07
673	0.05
CURVE 5	
373	0.00
473	0.02*
573	0.04*
673	0.06
773	0.09
873	0.12
973	0.15
1073	0.18
1173	0.21
1273	0.25*
1373	0.28*
1473	0.32*
1573	0.37
1643	0.40
CURVE 6	
1643	0.39
1573	0.34*
1473	0.39
1373	0.26*
1273	0.22*
1173	0.19*
CURVE 6 (cont.)	
1073	0.16*
973	0.12
873	0.10*
773	0.07*
673	0.04
CURVE 7	
373	0.01*
473	0.04
573	0.06
673	0.09
773	0.11
873	0.14
973	0.17
1073	0.20
1173	0.23
1273	0.27
1373	0.30
1473	0.34
1573	0.37*
1643	0.40*
CURVE 8	
1643	0.40*
1573	0.36*
1473	0.32*
1373	0.28*
1273	0.24
1173	0.21*
1073	0.18*
973	0.15*
873	0.12*
773	0.10*
673	0.07*
CURVE 9	
373	0.00*
473	0.02*
573	0.04*
673	0.07*
773	0.10*
873	0.13*
973	0.16*
CURVE 9 (cont.)	
1073	0.18*
1173	0.22*
1273	0.25*
1373	0.28*
1473	0.31
1573	0.35
1643	0.38*
CURVE 10	
1643	0.37
1573	0.33
1473	0.29
1373	0.26*
1273	0.22*
1173	0.19*
1073	0.16*
973	0.13*
873	0.10*
773	0.07*
673	0.05*
CURVE 11	
373	0.03
473	0.08
573	0.13
673	0.18
773	0.24
873	0.29
973	0.34
1073	0.40
1173	0.45
1273	0.51
1373	0.57
1473	0.63
1573	0.70
1643	0.74
CURVE 12	
1643	0.74*
1573	0.60
1473	0.61
1373	0.53
1273	0.47
CURVE 12 (cont.)	
1173	0.41
1073	0.35
973	0.29
873	0.24
773	0.19
673	0.14
CURVE 13	
373	0.02
473	0.07
573	0.12
673	0.17
773	0.22
873	0.28
973	0.34*
1073	0.39
1173	0.45*
1273	0.51*
1373	0.57*
1473	0.64
1573	0.70*
1643	0.75
CURVE 14	
1643	0.74*
1573	0.60*
1473	0.61*
1373	0.54
1273	0.48
1173	0.41*
1073	0.35*
973	0.30
873	0.24*
773	0.19*
673	0.13
CURVE 15	
373	0.03*
473	0.08*
573	0.13*
673	0.19
773	0.24*
873	0.30
CURVE 15 (cont.)	
973	0.36
1073	0.42
1173	0.48
1273	0.54
1373	0.61
1473	0.67
1573	0.74
1643	0.79
CURVE 16	
1643	0.78
1573	0.72
1473	0.65
1373	0.57*
1273	0.51*
1173	0.45*
1073	0.39*
973	0.33
873	0.28*
773	0.22*
673	0.17*
CURVE 17	
373	0.04
473	0.08*
573	0.13*
673	0.18*
773	0.24*
873	0.29*
973	0.34*
1073	0.40*
1173	0.46
1273	0.51*
1373	0.58
1473	0.64*
1573	0.70*
1643	0.74*
CURVE 18	
1643	0.74*
1573	0.68
1473	0.61*
1373	0.54*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 9. THERMAL LINEAR EXPANSION OF GRADE A GRAPHITE (continued)

T	$\Delta L/L_0$
CURVE 18 (cont.)	
1273	0.48*
1173	0.42
1073	0.36
973	0.31
873	0.25*
773	0.20
673	0.15
CURVE 19	
313	0.0068
373	0.0272*
473	0.0632*
573	0.1032
673	0.1472*
1273	0.4112
1473	0.4662
CURVE 19 (cont.)	
1673	0.5862
1873	0.7262
2073	0.8762
2273	1.0362
2473	1.2062
2673	1.3862
CURVE 20	
313	0.0086*
373	0.0344*
473	0.0864*
573	0.1424
673	0.1994*
1273	0.5414*
1473	0.6114*
1673	0.7614
CURVE 20 (cont.)	
1873	0.9314
2073	1.1114
2273	1.3014
2473	1.5114
2673	1.7214

DATA TABLE 9. COEFFICIENT OF THERMAL LINEAR EXPANSION OF GRADE A GRAPHITE

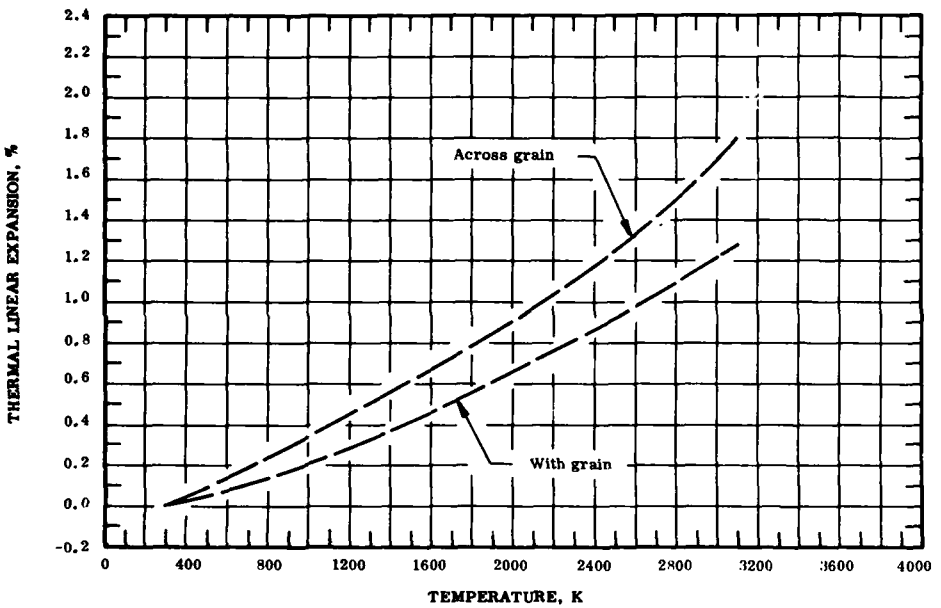
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
91	0.05
99	0.18
133	0.42
154	0.63
183	1.00
213	1.39
239	1.63
253	1.72
410	1.82*
639	2.17*
859	2.61*
1110	3.13*
1588	3.30*
1842	4.17*
2062	3.92*
2270	4.32*
CURVE 2‡	
87	0.55
110	0.93
131	1.38
157	2.13
187	2.96
207	3.44
230	3.84
255	4.12
408	4.22*
641	4.22*
876	4.86*
1112	5.13*
1581	5.48*
1831	5.9.*
2066	6.78*
2269	7.11*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 10R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE ATJ GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	5.0	0.000	2.2
400	0.055	5.0	0.025	2.5
600	0.156	5.0	0.079	2.9
800	0.255	5.1	0.140	3.3
1000	0.354	5.1	0.210	3.7
1200	0.454	5.2	0.286	4.0
1400	0.557	5.3	0.369	4.3
1600	0.665	5.6	0.459	4.6
1800	0.780	5.9	0.554	4.9
2000	0.903	6.4	0.654	5.1
2200	1.036	6.9	0.759	5.4
2400	1.181	7.6	0.868	5.5
2600	1.339	8.3	0.981	5.7
2800	1.513	9.1	1.096	5.9
3000	1.703	10.0	1.215	6.0
3100	1.805	10.4	1.275	6.0

REMARKS

The provisional values are considered accurate to within ± 7% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.158 + 5.651 \times 10^{-4} T - 8.817 \times 10^{-8} T^2 + 3.555 \times 10^{-11} T^3$

With grain: $\Delta L/L_0 = -0.055 + 1.552 \times 10^{-4} T + 1.205 \times 10^{-7} T^2 - 1.033 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 10%.

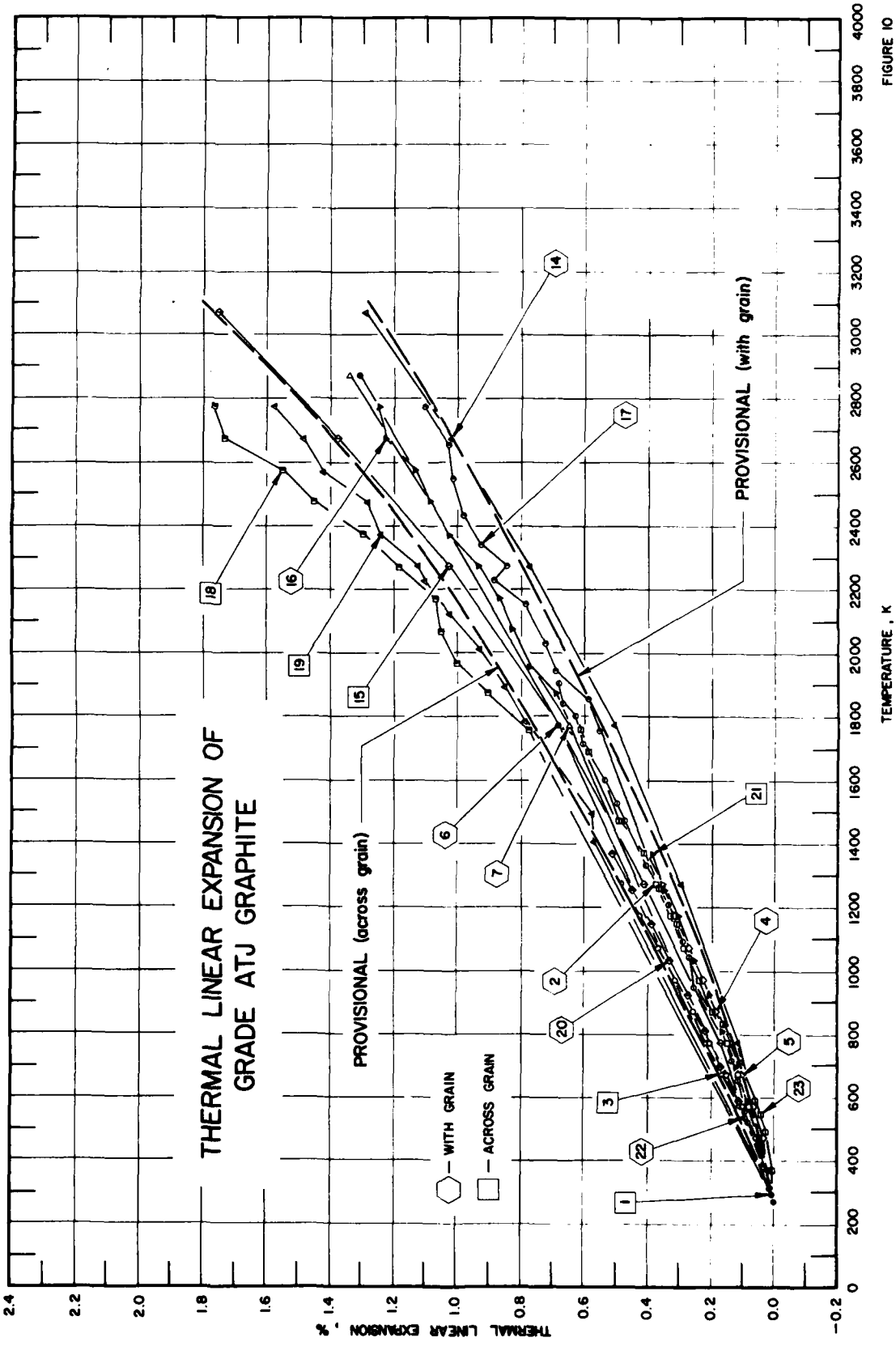

THERMAL LINEAR EXPANSION OF GRADE ATJ GRAPHITE
PROVISIONAL (with grain)
PROVISIONAL (across grain)
WITH GRAIN
ACROSS GRAIN
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000

FIGURE 10

SPECIFICATION TABLE 10. THERMAL LINEAR EXPANSION OF GRADE ATJ GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	369	Meyers, C. and Koyama, K.	1968	V	295-1273		Specimen cut from large bar supplied by Union Carbide and Chemical; expansion measured parallel to length of bar; zero-point correction of 0.001% determined by graphical extrapolation.
2	369	Meyers, C. and Koyama, K.	1968	V	295-1273		The above specimen; expansion measured perpendicular to length; zero-point correction of 0.001% determined by graphical extrapolation.
3	369	Meyers, C. and Koyama, K.	1968	V	295-1272		Similar to the above specimen; original block 8 x 18 x 50 in.; expansion measured in 8 in. direction; zero-point correction of 0.001% determined by graphical extrapolation.
4	369	Meyers, C. and Koyama, K.	1968	V	295-1274		The above specimen; expansion measured in 18 in. direction; zero-point correction of 0.000% determined by graphical extrapolation.
5	369	Meyers, C. and Koyama, K.	1968	V	295-1275		The above specimen; expansion measured in 50 in. direction; zero-point correction of 0.000% determined by graphical extrapolation.
6	370	Bradstreet, S.W.	1959		293-2873	Specimen No. 30	0.25 x 1 x 2 in. specimen; commercial molded, high-density (impregnated) graphite; obtained from National Carbon Co.; broad flat surface normal to direction of molding pressure.
7	370	Bradstreet, S.W.	1959		293-2873	Specimen No. 35	Specimen cut from the same block of material, the same way, as the above specimen.
8*	318	Neel, D.S., Pears, C.D. and Oglesby, S., Jr.	1962	L	294-2350	Run SRI-E19	Specimen 2.9920 in. long; obtained from National Carbon Co.; molded and fired; theoretically sublimes at 3866 K; density 110.3 lb. ft.$^{-3}$.
9*	318	Neel, D.S., et al.	1962	L	294-3214	Run SRI-E30	Rerun of above specimen; initial length 2.9909 in.; specimen showed permanent expansion after exposure to 3214 K.
10*	318	Neel, D.S., et al.	1962	L	3214-294		The above specimen; final length 2.9953 in.; expansion measured with decreasing temperature.
11*	318	Neel, D.S., et al.	1962	L	294-3289	Run SRI-E33	The above specimen; initial length 2.9960 in.; final length 2.9972 in.
12*	318	Neel, D.S., et al.	1962	L	294-2947	Run SRI-F34	Rerun of above specimen; initial length 2.9970 in.
13*	318	Neel, D.S., et al.	1962	L	2947-294	Run SRI-F34	Final length 2.9970 in.; expansion measured with decreasing temperature.
14	371	Dull, R.B.	1964	O/T	293-3073		Specimens obtained from National Carbon Co.; expansion measured parallel to grain orientation with optical lever from 293-373 K of 0.3 x 3/8 x 5 in. specimen and with telemicroscope for high temperature of 1/2 x 1/2 x 2 in. specimen; data average of several runs.
15	371	Dull, R.B.	1964	O/T	293-3073		The above specimen; expansion measured across grain orientation.
16	372	Lund, H.H. and Bortz, S.A.	1960	L	293-2773	ATJ-30	Specimen obtained from National Carbon Co.; original length 2 in.; molded; expansion measured parallel to the basal plane with increasing temperature.
17	372	Lund, H.H. and Bortz, S.A.	1960	L	2773-273	ATJ-30	The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.137% determined by graphical interpolation.
18	372	Lund, H.H. and Bortz, S.A.	1960	L	293-2773	ATJ-24	Specimen obtained from National Carbon Co.; original length 2 in.; molded; expansion measured perpendicular to basal plane with increasing temperature.
19	372	Lund, H.H. and Bortz, S.A.	1960	L	2773-273	ATJ-24	The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.190% determined by graphical interpolation.

* Not shown in figure.

SPECIFICATION TABLE 10. THERMAL LINEAR EXPANSION OF GRADE ATJ GRAPHITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
20	368	Allen, R. D.	1959	L	300-1367	Block No. 0801	Specimen 1/4 in. dia, 2 in. long; obtained from National Carbon Co. ; max filler particle size 0. 005 in. ; petroleum coke mixed with coal tar pitch; impregnated with coal tar pitch, molded, and graphitized at 3033 K.
21	368	Allen, R. D.	1959	L	300-1367	Block No. 0801	The above specimen except expansion measured perpendicular to grain direction.
22	373	Fieldhouse, I. B., Lang, J. I. and Blau, H. H., Jr.	1960	T	294-1905	Siliconized ATJ graphite; Sample 1	0. 2 ash; max grain size 0. 006 in. ; expansion measured parallel to grain orientation; reported error <3%.
23	373	Fieldhouse, I. B., et al.	1960	T	294-1802	Siliconized ATJ graphite; Sample 2	Similar to the above specimen; reported error <3%.
24*	374	Anthony, F. M. and Pearl, H. A.	1960	L	299-1652	Coated ATJ graphite	Specimen 3/8 in. dia, 3 in. long; max grain size 0. 006 in. ; ash content 0. 2%; molded; coating applied essentially is a diffusioned deposit of SiC.
25*	375	Turner, J. H. and Carter, M. B.	1964		293, 373	w. g.	Specimen 1/2 x 1/2 x 1 in.
26*	375	Turner, J. H. and Carter, M. B.	1964		293, 373	a. g.	Similar to the above specimen.

* Not shown in figure.

DATA TABLE 10. THERMAL LINEAR EXPANSION OF GRADE ATJ GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
295	0.001
373	0.023
473	0.056
572	0.100
671	0.150
773	0.202
874	0.257
972	0.313
1072	0.368
1173	0.426
1273	0.483
CURVE 2	
295	0.001*
373	0.019*
473	0.046
572	0.080
673	0.112
773	0.150
874	0.195
973	0.239
1073	0.284
1173	0.329
1273	0.376
CURVE 3	
295	0.001*
374	0.026*
473	0.064*
575	0.110
673	0.163
775	0.212
873	0.264*
973	0.317*
1073	0.371*
1172	0.430*
1272	0.484*
CURVE 4	
295	0.000*
374	0.013*
473	0.034
573	0.065
673	0.103*
772	0.142*
873	0.184
973	0.227
1073	0.270
1172	0.317
1274	0.368*
CURVE 5	
295	0.000*
373	0.014*
473	0.034*
573	0.063*
673	0.100
774	0.138
873	0.180*
972	0.220*
1073	0.260*
1173	0.305
1275	0.351
CURVE 6	
293	0.00*
1773	0.68
2873	1.31
CURVE 7	
293	0.00*
1773	0.65
2873	1.34
CURVE 8*	
294	0.00
1049	0.20
1105	0.22
1283	0.29
1516	0.36
1616	0.39
1727	0.45
1838	0.49
1922	0.53
2044	0.59
2222	0.68
2349	0.74
CURVE 9*	
293	0.00
866	0.14
1019	0.20
1266	0.28
1438	0.36
1616	0.42
1744	0.47
1944	0.54
2138	0.62
2366	0.72
2680	0.80
2947	0.93
3107	1.07
3214	1.11
CURVE 10*	
3214	1.08
2266	0.59
1560	0.29
294	0.00
CURVE 11*	
293	0.00
588	0.13
860	0.22
1149	0.35
1422	0.48
1699	0.60
1838	0.71
2066	0.84
2283	0.97
2449	1.08
2834	1.18
2843	1.20
2989	1.32
3161	1.44
3244	1.51
3289	1.58
CURVE 12*	
294	0.00
1033	0.28
1088	0.31
1344	0.45
1633	0.60
1963	0.78
2199	0.92
2449	1.07
2947	1.25
CURVE 13*	
2947	1.26
2460	1.05
2199	0.86
1722	0.59
1155	0.29
294	0.00
CURVE 14	
293	0.000*
773	0.117
1273	0.292
1773	0.507
2273	0.772
2673	1.020
3073	1.291
CURVE 15	
293	0.000*
773	0.168
1273	0.411
1773	0.684*
2273	1.029
2673	1.379
3073	1.754
CURVE 16	
293	0.000*
1763	0.652*
1873	0.691
1958	0.774
2074	0.829
2173	0.868
2273	0.937
2369	1.026
2478	1.087
2578	1.138
2673	1.228
2773	1.244
CURVE 17	
2773	1.107
2653	1.031
2544	1.013
2431	0.983
2340	0.924
2273	0.843
2226	0.881
2158	0.782
2028	0.721
1941	0.692
1851	0.588
1758	0.552
273	-0.005
CURVE 18	
293	0.000*
1758	0.780
1873	0.909
1966	1.004
2068	1.051
2173	1.071
2270	1.183
2373	1.299
2478	1.457
2573	1.559
2673	1.736
2773	1.770
CURVE 19	
2773	1.580
2673	1.487
2568	1.426
2473	1.284
2373	1.241
2273	1.127
2223	1.102
2121	1.025
2010	0.932
1896	0.853
1783	0.790
1494	0.576
1405	0.570
273	-0.003*
CURVE 20	
299	0.002*
477	0.067*
588	0.116
699	0.168
810	0.218
922	0.274
1033	0.330
1144	0.389
1255	0.449
1366	0.512
CURVE 21	
299	0.002*
477	0.050*
588	0.085
699	0.122
810	0.165
922	0.207
1033	0.253
1144	0.299*
1255	0.346
1366	0.386
CURVE 22	
294	0.000*
316	0.010
383	0.030
522	0.080
538	0.090
555	0.090
655	0.115
713	0.135

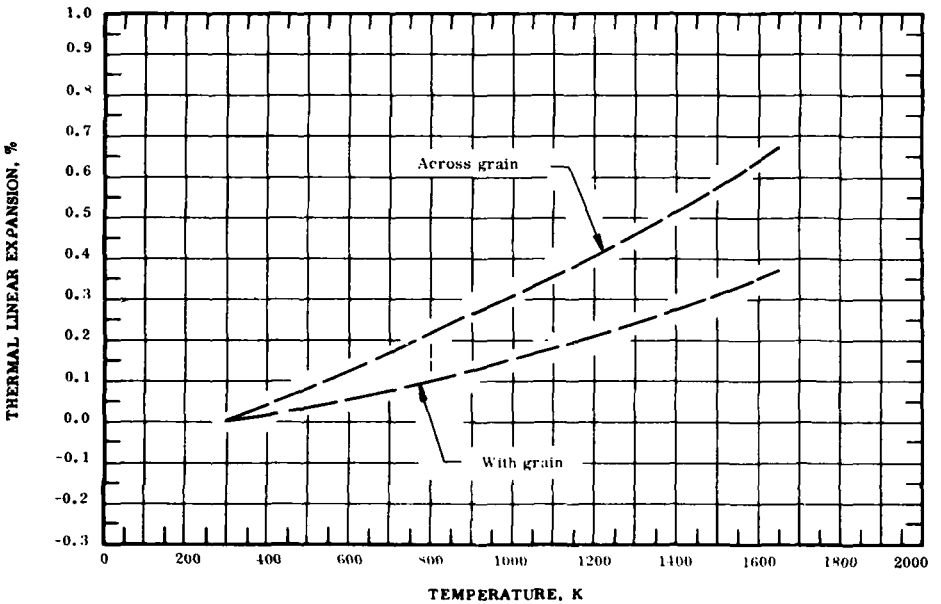
* Not shown in figure.

DATA TABLE 10. THERMAL LINEAR EXPANSION OF GRADE ATJ GRAPHITE (continued)

T	$\Delta L/L_0$
CURVE 22 (cont.)	
777	0.155*
952	0.255
1044	0.265
1094	0.290
1160	0.315*
1208	0.335
1322	0.405
1472	0.475
1530	0.495
1602	0.535
1719	0.605
1805	0.630
1844	0.667
1905	0.680
CURVE 23	
294	0.000*
366	0.001
494	0.027
544	0.040
588	0.060
708	0.107
766	0.125*
833	0.160
922	0.205*
1033	0.245*
1147	0.305
1260	0.367
1372	0.417
1477	0.493
1605	0.527*
1694	0.590
1760	0.610
1802	0.630*
CURVE 24*	
299	0.005
830	0.172
1255	0.439
1652	0.515
CURVE 25*	
293	0.00
373	0.018
CURVE 26*	
293	0.00
373	0.028

* Not shown in figure.

FIGURE AND TABLE NO. 11R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE B GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	4.0	0.000	1.6
400	0.043	4.1	0.018	1.7
600	0.126	4.2	0.056	2.1
800	0.213	4.5	0.100	2.4
1000	0.258	4.8	0.152	2.7
1200	0.405	5.2	0.210	3.1
1400	0.515	5.8	0.276	3.5
1600	0.637	6.4	0.351	3.9
1650	0.669	6.6	0.370	4.0

REMARKS

The provisional values are considered accurate to within ±7% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.117 + 4.029 \times 10^{-4} T - 1.906 \times 10^{-7} T^2 + 3.863 \times 10^{-11} T^3$

With grain: $\Delta L/L_0 = -0.040 + 1.180 \times 10^{-4} T + 6.621 \times 10^{-8} T^2 + 8.025 \times 10^{-12} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

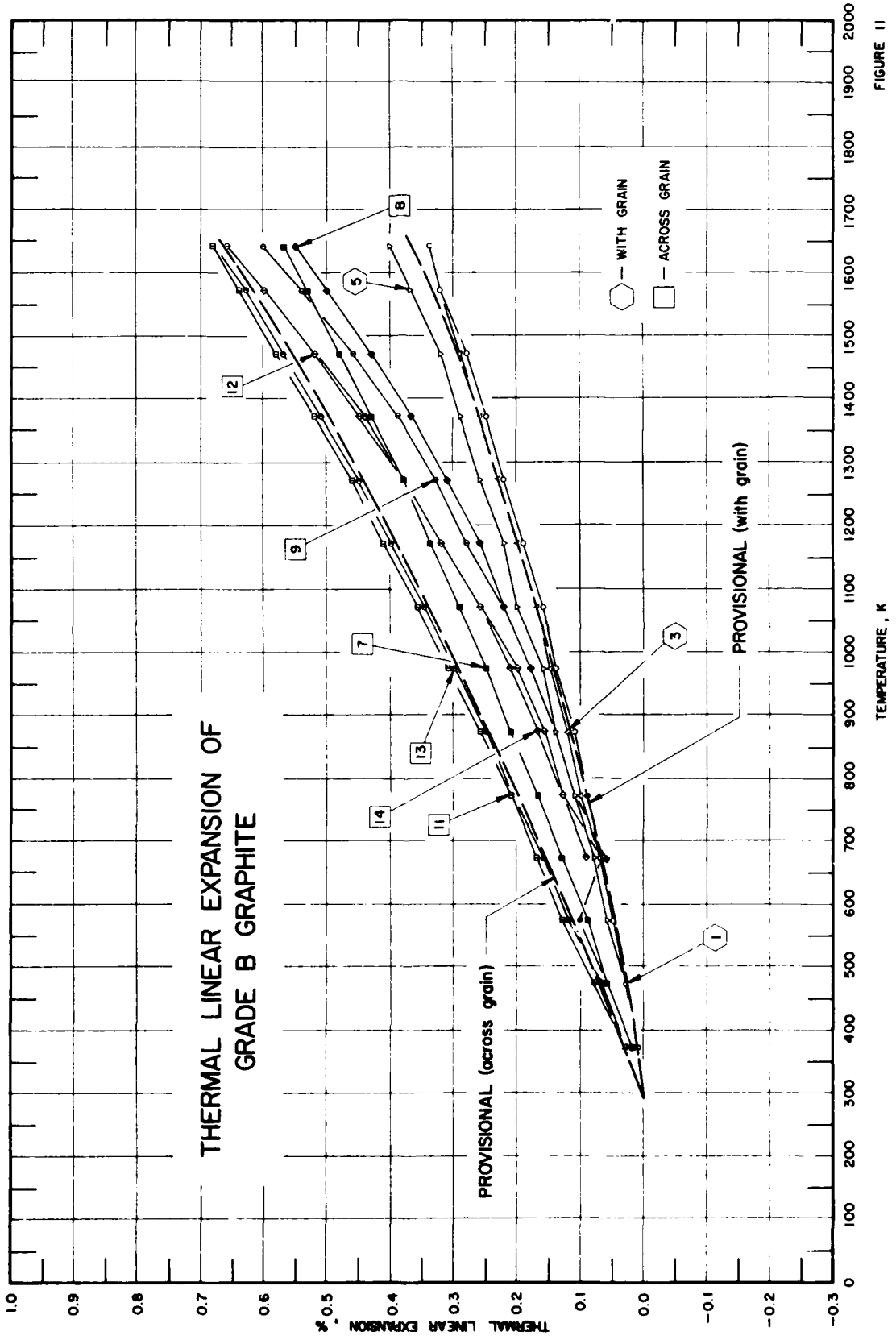

THERMAL LINEAR EXPANSION OF
GRADE B GRAPHITE
PROVISIONAL (with grain)
PROVISIONAL (across grain)
— WITH GRAIN
— ACROSS GRAIN
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 11

SPECIFICATION TABLE 11. THERMAL LINEAR EXPANSION OF GRADE B GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	164	Burdick, M. D., Zweig, B., and Moreland, R. E.	1951	L	373-1643	Specimen A_1 Test No. 28	Extruded; right cylindrical specimen, ~0.375 in. diameter, 2 in. long; cut parallel to extrusion direction; reported error ±0.02%.
2*	164	Burdick, M. D., et al.	1951	L	1643-673	Specimen A_1 Test No. 28	The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.05%.
3	164	Burdick, M. D., et al.	1951	L	373-1643	Specimen A_1 Test No. 40	The above specimen; expansion measured with increasing temperature.
4*	164	Burdick, M. D., et al.	1951	L	1643-773	Specimen A_1 Test No. 40	The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.08%.
5	164	Burdick, M. D., et al.	1951	L	373-1643	Specimen A_2 Test No. 33	Similar to the above specimen; expansion measured with increasing temperature.
6*	164	Burdick, M. D., et al.	1951	L	1643-673	Specimen A_2 Test No. 33	The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.05%.
7	164	Burdick, M. D., et al.	1951	L	373-1643	Specimen L_1 Test No. 34	Similar to the above specimen except cut perpendicular to extrusion direction; expansion measured with increasing temperature.
8	164	Burdick, M. D., et al.	1951	L	1643-673	Specimen L_1 Test No. 34	The above specimen; expansion measured with decreasing temperature.
9	164	Burdick, M. D., et al.	1951	L	373-1643	Specimen L_2 Test No. 35	Similar to the above specimen; expansion measured with increasing temperature.
10*	164	Burdick, M. D., et al.	1951	L	1643-673	Specimen L_2 Test No. 35	The above specimen; expansion measured with decreasing temperature.
11	164	Burdick, M. D., et al.	1951	L	373-1643	Specimen U Test No. 36	Similar to the above specimen; expansion measured with increasing temperature.
12	164	Burdick, M. D., et al.	1951	L	1643-673	Specimen U Test No. 36	The above specimen; expansion measured with decreasing temperature.
13	164	Burdick, M. D., et al.	1951	L	373-1643	Specimen T Test No. 37	Similar to the above specimen; expansion measured with increasing temperature.
14	164	Burdick, M. D., et al.	1951	L	1643-673	Specimen T Test No. 37	The above specimen; expansion measured with decreasing temperature.
15*	403	Volk, H. F., Epremian, E., and Criscione, J. M.	1963	L	313-2673		Expansion measured in direction I.
16*	403	Volk, H. F., et al.	1963	L	313-2673		Expansion measured in direction II.
17*	403	Volk, H. F., et al.	1963	L	313-2673		Expansion measured in direction III.

* Not shown in figure.

DATA TABLE 11. THERMAL LINEAR EXPANSION OF GRADE B GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
373	0.01
473	0.03
573	0.05
673	0.07
773	0.09
873	0.11
973	0.14
1073	0.16
1173	0.19
1273	0.22
1373	0.25
1473	0.28
1573	0.32
1643	0.34
CURVE 2*	
1643	0.38
1573	0.34
1473	0.29
1373	0.25
1273	0.22
1173	0.19
1073	0.16
973	0.14
873	0.11
773	0.09
673	0.07
CURVE 3	
373	0.01*
473	0.03*
573	0.05*
673	0.07*
773	0.10
873	0.12
973	0.15
1073	0.17
1173	0.20
1273	0.23
1373	0.26
1473	0.29
1573	0.32*
1643	0.34*

T	$\Delta L/L_0$
CURVE 4*	
1643	0.38
1573	0.34
1473	0.29
1373	0.24
1273	0.23
1173	0.18
1073	0.15
973	0.13
873	0.10
773	0.08
CURVE 5	
373	0.01*
473	0.03*
573	0.06
673	0.08
773	0.11
873	0.14
973	0.16
1073	0.20
1173	0.22
1273	0.26
1373	0.29
1473	0.32
1573	0.37
1643	0.40
CURVE 6*	
1643	0.43
1573	0.39
1473	0.33
1373	0.29
1273	0.25
1173	0.21
1073	0.17
973	0.15
873	0.12
773	0.09
673	0.07
CURVE 7	
373	0.02
473	0.06

T	$\Delta L/L_0$
CURVE 7 (cont.)	
573	0.09
673	0.13
773	0.17
873	0.21
973	0.25
1073	0.29
1173	0.34
1273	0.38
1373	0.43
1473	0.48
1573	0.53
1643	0.57
CURVE 8	
1643	0.55
1573	0.50
1473	0.43
1373	0.37
1273	0.31
1173	0.26
1073	0.22
973	0.18
873	0.14*
773	0.10*
673	0.06
CURVE 9	
373	0.02*
473	0.06*
573	0.10
673	0.07*
773	0.10*
873	0.14*
973	0.18*
1073	0.22*
1173	0.28
1273	0.33
1373	0.39
1473	0.46
1573	0.54
1643	0.60

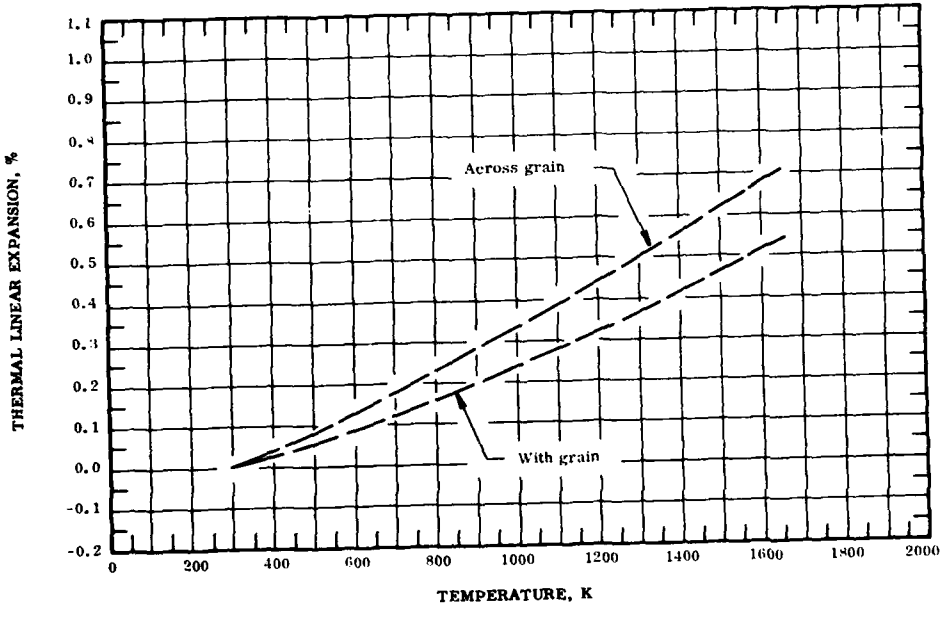
T	$\Delta L/L_0$
CURVE 10*	
1643	0.60
1573	0.54
1473	0.46
1373	0.39
1273	0.33
1173	0.28
1073	0.22
973	0.18
873	0.14
773	0.10
676	0.07
CURVE 11	
373	0.03
473	0.08
573	0.13
673	0.17
773	0.21
873	0.26
973	0.31
1073	0.36
1173	0.41
1273	0.46
1373	0.52
1473	0.58
1573	0.64
1643	0.68
CURVE 12	
1643	0.66
1573	0.60
1473	0.52
1373	0.45
1273	0.38*
1173	0.32
1073	0.26
973	0.20
873	0.16
773	0.13
673	0.07*
CURVE 13	
373	0.03*

T	$\Delta L/L_0$
CURVE 13 (cont.)	
473	0.07
573	0.12
673	0.16
773	0.21*
873	0.25
973	0.30
1073	0.35
1173	0.40
1273	0.45
1373	0.51
1473	0.57
1573	0.63
1643	0.68*
CURVE 14	
1643	0.66*
1573	0.60*
1473	0.52*
1373	0.44
1273	0.38*
1173	0.32*
1073	0.26*
973	0.21
873	0.17
773	0.13*
673	0.09
CURVE 15*	
313	0.011
373	0.043
473	0.105
573	0.169
673	0.241
1273	0.673
1473	0.755
1673	0.933
1873	1.117
2073	1.307
2273	1.509
2473	1.713
2673	1.925

T	$\Delta L/L_0$
CURVE 16*	
313	0.008
373	0.033
473	0.086
573	0.143
673	0.203
1273	0.563
1473	0.639
1673	0.796
1873	0.965
2073	1.137
2273	1.317
2473	1.503
2673	1.695
CURVE 17*	
313	0.009
373	0.036
473	0.089
573	0.143
673	0.202
1273	0.556
1473	0.636
1673	0.802
1873	0.972
2073	1.148
2273	1.328
2473	1.514
2673	1.704

* Not shown in figure.

FIGURE AND TABLE NO. 12R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE C GRAPHITE



PROVISIONAL VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	4.0	0.000	2.6
400	0.045	4.3	0.029	2.8
600	0.134	4.7	0.090	3.3
800	0.231	5.0	0.160	3.7
1000	0.335	5.4	0.238	4.1
1200	0.445	5.6	0.323	4.4
1400	0.560	5.9	0.414	4.7
1600	0.680	6.1	0.510	4.9
1650	0.711	6.1	0.534	5.0

REMARKS

The provisional values are considered accurate to within ±7% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.109 + 3.368 \times 10^{-4} T + 1.233 \times 10^{-7} T^2 - 1.599 \times 10^{-11} T^3$

With grain: $\Delta L/L_0 = -0.063 + 1.756 \times 10^{-4} T + 1.453 \times 10^{-7} T^2 - 1.944 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

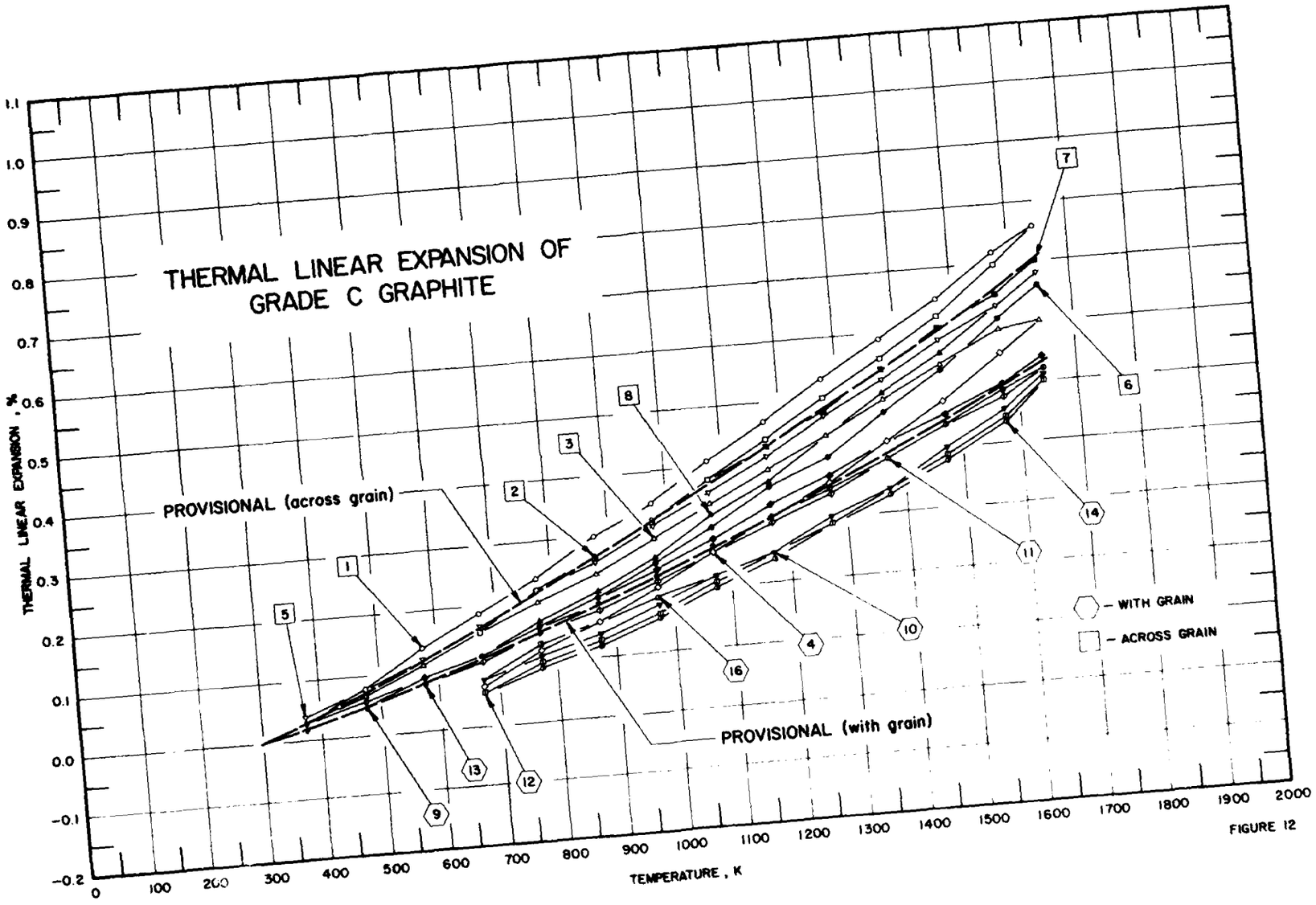

THERMAL LINEAR EXPANSION OF
GRADE C GRAPHITE
PROVISIONAL (across grain)
PROVISIONAL (with grain)
WITH GRAIN
ACROSS GRAIN
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
4
5
6
7
8
9
10
11
12
13
14
16

FIGURE 12

SPECIFICATION TABLE 12. THERMAL LINEAR EXPANSION OF GRADE C GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	164	Burdick, M.D., Zweig, B., and Moreland, R.E.	1951	L	373-1643	Specimen A_1 Test No. 22	Right cylindrical specimen, 0.375 in. diameter, 2 in. long; cut in molding pressure direction; reported error ± 0.02%.
2	164	Burdick, M.D., et al.	1951	L	1643-673	Specimen A_1 Test No. 22	The above specimen; expansion measured with decreasing temperature.
3	164	Burdick, M.D., et al.	1951	L	373-1643	Specimen A_2 Test No. 23	Similar to the above specimen; expansion measured with increasing temperature.
4	164	Burdick, M.D., et al.	1951	L	1643-673	Specimen A_2 Test No. 23	The above specimen; expansion measured with decreasing temperature.
5	164	Burdick, M.D., et al.	1951	L	373-1643	Specimen B_1 Test No. 29	Similar to the above specimen; expansion measured with increasing temperature.
6	164	Burdick, M.D., et al.	1951	L	1643-673	Specimen B_1 Test No. 29	The above specimen; expansion measured with decreasing temperature.
7	164	Burdick, M.D., et al.	1951	L	373-1643	Specimen B_2 Test No. 32	Similar to the above specimen; expansion measured with increasing temperature.
8	164	Burdick, M.D., et al.	1951	L	1643-673	Specimen B_2 Test No. 32	The above specimen; expansion measured with decreasing temperature.
9	164	Burdick, M.D., et al.	1951	L	373-1643	Specimen T_1 Test No. 24	Similar to the above specimen except cut perpendicular to direction of molding pressure; expansion measured with increasing temperature.
10	164	Burdick, M.D., et al.	1951	L	1643-673	Specimen T_1 Test No. 24	The above specimen; expansion measured with decreasing temperature; held at 1390 K for 45 min. before cooling.
11	164	Burdick, M.D., et al.	1951	L	373-1643	Specimen T_2 Test No. 25	Similar to the above specimen; expansion measured with increasing temperature.
12	164	Burdick, M.D., et al.	1951	L	1643-673	Specimen T_2 Test No. 25	The above specimen; expansion measured with decreasing temperature.
13	164	Burdick, M.D., et al.	1951	L	373-1643	Specimen L_1 Test No. 26	Similar to the above specimen; expansion measured with increasing temperature.
14	164	Burdick, M.D., et al.	1951	L	1643-673	Specimen J_1 Test No. 26	The above specimen; expansion measured with decreasing temperature.
15*	164	Burdick, M.D., et al.	1951	L	373-1643	Specimen L_2 Test No. 27	Similar to the above specimen; expansion measured with increasing temperature.
16	164	Burdick, M.D., et al.	1951	L	1643-673	Specimen L_2 Test No. 27	The above specimen; expansion measured with decreasing temperature.

* Not shown in figure.

DATA TABLE 12. THERMAL LINEAR EXPANSION OF GRADE C GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
373	0.03
473	0.08
573	0.14
673	0.19
773	0.24
873	0.30
973	0.35
1073	0.41
1173	0.47
1273	0.53
1373	0.59
1473	0.65
1573	0.72
1643	0.76
CURVE 2	
1643	0.76*
1573	0.70
1473	0.62
1373	0.56
1273	0.50
1173	0.44
1073	0.38
973	0.32
873	0.27
773	0.22
673	0.16
CURVE 3	
373	0.03*
473	0.07
573	0.11
673	0.16*
773	0.20
873	0.24
973	0.29
1073	0.34
1173	0.39
1273	0.44
1373	0.49
1473	0.54
1573	0.59
1643	0.60

T	$\Delta L/L_0$
CURVE 4	
1643	0.60*
1573	0.55
1473	0.48
1373	0.42
1273	0.36
1173	0.31
1073	0.26
973	0.21
873	0.16
773	0.12
673	0.07
CURVE 5	
373	0.04
473	0.08*
573	0.12
673	0.17
773	0.22*
873	0.26
973	0.31
1073	0.36
1173	0.41
1273	0.47
1373	0.52
1473	0.58
1573	0.63
1643	0.68
CURVE 6	
1643	0.66
1573	0.61
1473	0.53
1373	0.47
1273	0.40
1173	0.36
1073	0.30
973	0.25
873	0.20
773	0.16
673	0.12

T	$\Delta L/L_0$
CURVE 7	
373	0.03*
473	0.08*
573	0.12*
673	0.17*
773	0.22*
873	0.27*
973	0.32*
1073	0.38*
1173	0.43
1273	0.48
1373	0.54
1473	0.60
1573	0.65
1643	0.70
CURVE 8	
1643	0.68*
1573	0.63*
1473	0.56
1373	0.50
1273	0.44*
1173	0.37
1073	0.32
973	0.26
873	0.21
773	0.17
673	0.12*
CURVE 9	
373	0.02
473	0.05
573	0.09
673	0.12*
773	0.16*
873	0.20*
973	0.24
1073	0.28
1173	0.33
1273	0.37
1373	0.42*
1473	0.46
1573	0.50
1643	0.54

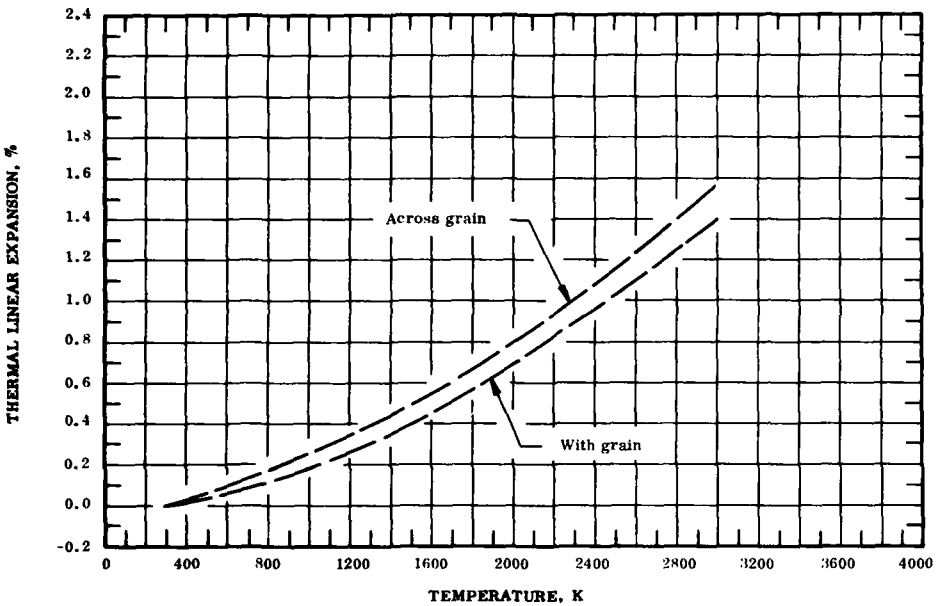
T	$\Delta L/L_0$
CURVE 10	
1643	0.51
1573	0.46
1473	0.40
1373	0.34
1273	0.30
1173	0.25
1073	0.22
973	0.18
873	0.14
773	0.11
673	0.08
CURVE 11	
373	0.03*
473	0.06
573	0.09*
673	0.12*
773	0.16*
873	0.19
973	0.23
1073	0.27
1173	0.31*
1273	0.35
1373	0.39
1473	0.44
1573	0.49
1643	0.52
CURVE 12	
1643	0.50
1573	0.45
1473	0.39
1373	0.34*
1273	0.29
1173	0.25*
1073	0.21
973	0.17
873	0.13
773	0.10
673	0.06

T	$\Delta L/L_0$
CURVE 13	
373	0.02*
473	0.05*
573	0.08
673	0.11
773	0.15
873	0.18
973	0.22
1073	0.26*
1173	0.30
1273	0.34
1373	0.39*
1473	0.44*
1573	0.48
1643	0.52*
CURVE 14	
1643	0.50*
1573	0.44
1473	0.38
1373	0.33
1273	0.29*
1173	0.24
1073	0.20
973	0.16
873	0.12
773	0.09
673	0.06*
CURVE 15*	
373	0.02
473	0.05
573	0.09
673	0.12
773	0.15
873	0.19
973	0.23
1073	0.26
1173	0.30
1273	0.35
1373	0.39
1473	0.44
1573	0.48
1643	0.52

T	$\Delta L/L_0$
CURVE 16	
1643	0.50*
1573	0.44*
1473	0.39*
1373	0.34*
1273	0.29*
1173	0.25*
1073	0.22*
973	0.19
873	0.16*
773	0.13
673	0.08*

* Not shown in figure.

FIGURE AND TABLE NO. 13R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE CFW GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	2.5	0.000	1.1
400	0.028	2.8	0.014	1.5
600	0.089	3.3	0.052	2.3
800	0.160	3.8	0.105	3.0
1000	0.240	4.3	0.172	3.7
1200	0.331	4.8	0.252	4.3
1400	0.432	5.3	0.344	4.9
1600	0.541	5.7	0.446	5.4
1800	0.680	6.2	0.559	5.9
2000	0.787	6.6	0.681	6.3
2200	0.924	7.0	0.811	6.7
2400	1.068	7.4	0.948	7.0
2600	1.221	7.8	1.091	7.3
2800	1.381	8.2	1.239	7.5
3000	1.549	8.6	1.391	7.7

REMARKS

The provisional values are considered accurate to within ±10% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.061 + 1.687 \times 10^{-4}\ T + 1.380 \times 10^{-7}\ T^2 - 5.128 \times 10^{-12}\ T^3$

With grain: $\Delta L/L_0 = -0.014 - 1.614 \times 10^{-5}\ T + 2.223 \times 10^{-7}\ T^2 - 2.027 \times 10^{-11}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

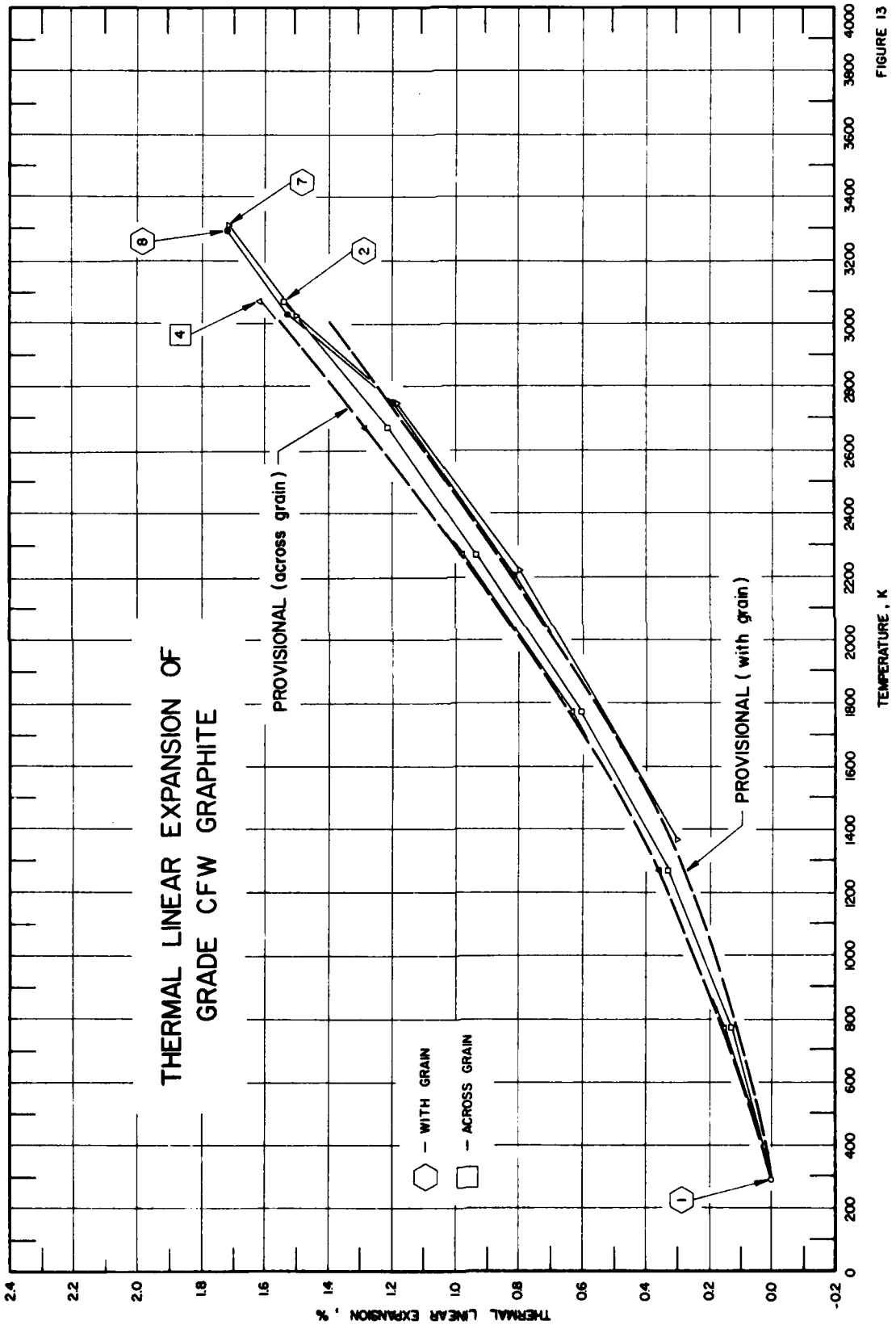

THERMAL LINEAR EXPANSION OF
GRADE CFW GRAPHITE
PROVISIONAL (across grain)
PROVISIONAL (with grain)
— WITH GRAIN
— ACROSS GRAIN
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
1
2
4
7
8

FIGURE 13

SPECIFICATION TABLE 13. THERMAL LINEAR EXPANSION OF GRADE CFW GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	371	Dull, R. B.	1964	O	293, 373		National Carbon Co.; specimen 0.3 x 0.375 x 5 in.; specimen taken from 40-in. outside dia by 15-in. inside dia by 20-in. long block; bulk density 1.90 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 11.98×10^{-4} ohm-cm, across grain 12.60×10^{-4} ohm-cm; average data over several runs; expansion measured parallel to grain.
2	371	Dull, R. B.	1964	O/T	293-3073		Specimen taken from same block as above specimen; specimen 0.5 x 0.5 x 5 in.; expansion measured parallel to grain.
3*	371	Dull, R. B.	1964	O	293, 373		Specimen taken from same block as above specimen; specimen 0.3 x 0.375 x 5 in.; expansion measured across grain.
4	371	Dull, R. B.	1964	O, T	293-3073		Specimen taken from same block as above specimen; specimen 0.5 x 0.5 x 5 in.; expansion measured across grain.
5*	375	Turner, J. H. and Carter, M. B.	1964		293, 373		Specimen 0.5 x 0.5 x 1 in., impregnated grade ATL; larger grain size.
6*	375	Turner, J. H. and Carter, M. B.	1964		293, 373		The above specimen except expansion measured across grain.
7	378	Dull, R. B.	1964	T	1367-3317	Specimen B-33B	Expansion measured parallel to grain with increasing temperature.
8	378	Dull, R. B.	1964	T	1367-3300	Specimen B-44A	Expansion measured parallel to grain with increasing temperature.

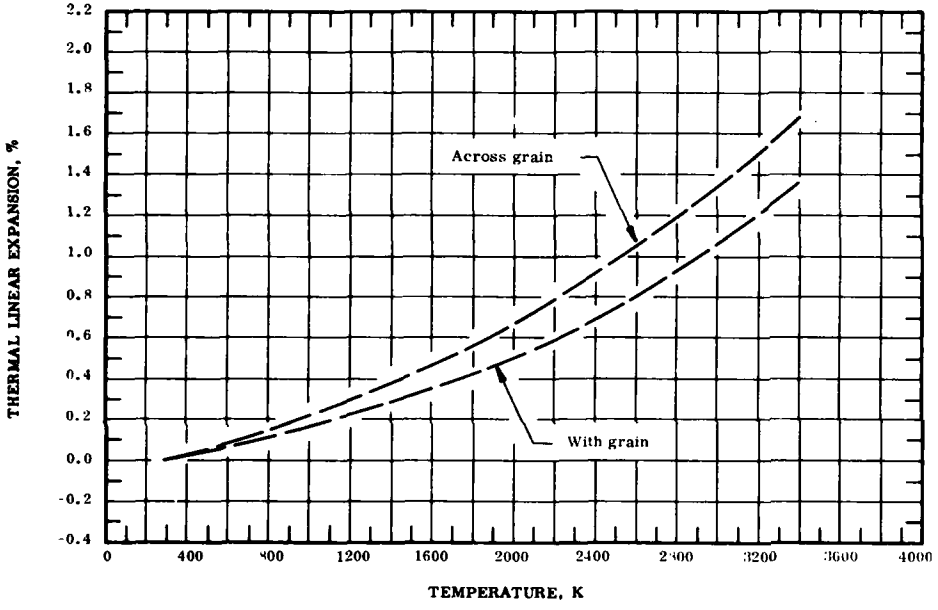
DATA TABLE 13. THERMAL LINEAR EXPANSION OF GRADE CFW GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
373	0.019
CURVE 2	
293	0.000
773	0.133
1273	0.339
1773	0.608
2273	0.934
2673	1.210
3073	1.542
CURVE 3*	
293	0.000
373	0.022
CURVE 4	
293	0.000
773	0.154
1273	0.361
1773	0.633
2273	0.974
2673	1.282
3073	1.619
CURVE 5*	
293	0.00
373	0.02
CURVE 6*	
293	0.00
373	0.02
CURVE 7	
1367	0.306
2222	0.792
CURVE 7 (cont.)	
2750	1.183
3028	1.502
3317	1.717
CURVE 8	
1367	0.300
2206	0.811
2755	1.197
3033	1.532
3300	1.721

* Not shown in figure.

FIGURE AND TABLE NO. 14R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE CFZ GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	2.3	0.000	2.1
400	0.026	2.5	0.024	2.2
600	0.079	2.9	0.070	2.3
800	0.140	3.2	0.118	2.5
1000	0.208	3.6	0.170	2.7
1200	0.284	4.0	0.226	2.9
1400	0.368	4.4	0.286	3.2
1600	0.459	4.8	0.353	3.5
1800	0.559	5.2	0.427	3.9
2000	0.667	5.6	0.508	4.3
2200	0.784	6.0	0.598	4.7
2400	0.909	6.5	0.698	5.2
2600	1.043	6.9	0.807	5.8
2800	1.186	7.4	0.928	6.3
3000	1.339	7.9	1.061	7.0
3200	1.500	8.3	1.207	7.6
3400	1.672	8.8	1.367	8.4

REMARKS

The provisional values are considered accurate to within ±10% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.060 + 1.809 \times 10^{-4} T + 8.394 \times 10^{-8} T^2 + 3.734 \times 10^{-12} T^3$

With grain: $\Delta L/L_0 = -0.064 + 2.182 \times 10^{-4} T - 2.589 \times 10^{-8} T^2 + 1.831 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

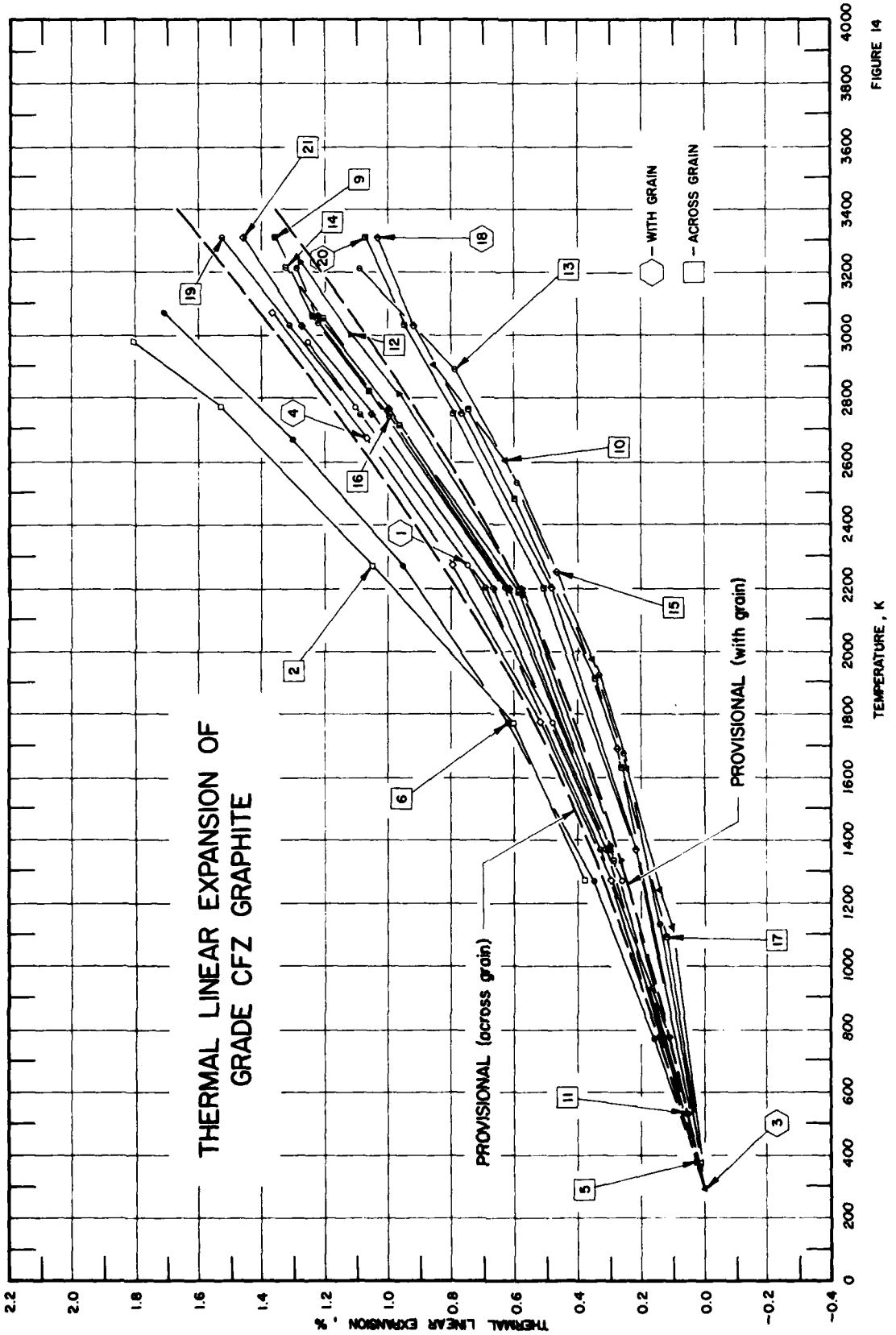

THERMAL LINEAR EXPANSION OF
GRADE CFZ GRAPHITE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
WITH GRAIN
ACROSS GRAIN
PROVISIONAL (with grain)
PROVISIONAL (across grain)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000

FIGURE 14

SPECIFICATION TABLE 14. THERMAL LINEAR EXPANSION OF GRADE CFZ GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	379	Lafyatis, P.G., Waters, C.W., and Dull, R.B.	1965	T	1273-2980		Material formed in cylinders 58 in. O.D., 30 in. I.D., 40 in. long; eight specimens cut to 0.50 x 0.50 x 5 in. and tested; average results given for expansion with grain; reported error 5.0%.
2	379	Lafyatis, P.C., et al.	1965	T	1273-2980		The above specimen except expansion measured across grain.
3	371	Dull, R.B.	1964	O	293, 373		Specimen obtained from National Carbon Co.; dimensions 0.3 x 0.375 x 5 in.; specimen taken from 14 in. diameter, 13.5 in. long block; bulk density 1.91 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 12.77 x 10^{-4} ohm cm, across grain 16.08 x 10^{-4} ohm cm; expansion measured parallel to grain; average data over several runs.
4	371	Dull, R.B.	1964	O/T	293-3073		Specimen taken from same block as above specimen; specimen dimensions 0.50 x 0.50 x 5 in.; expansion measured parallel to grain.
5	371	Dull, . .B.	1964	O	293, 373		Specimen taken from same block as above specimen; specimen dimensions 0.3 x 0.375 x 5 in.; expansion measured across grain.
6	371	Dull, R.B.	1964	O/T	293-3073		Specimen taken from same block as above specimen; specimen dimensions 0.50 x 0.50 x 5 in.; expansion measured across grain.
7*	375	Turner, T.H. and Carter, M.B.	1964		293, 373		Specimen 0.50 x 0.50 x 1 in.; obtained by impregnating RVA graphite; expansion measured with grain.
8*	375	Turner, T.H. and Carter, M.B.	1964		293, 373		Similar to the above specimen; expansion measured across grain.
9	380	Southern Research Institute	1964	L	294-3311	CFZ-2A3h-aE11	Specimen initial length 3.0031 in.; bulk density 1.897 g cm^{-3}; expansion measured across grain.
10	380	Southern Research Institute	1964	L	2908-294	CFZ-2A3h-aE11	The above specimen; expansion measured with decreasing temperature; final length at 294 K 3.0095 in; zero-point correction of -0.25% determined by graphical extrapolation.
11	380	Southern Research Institute	1964	L	294-3061	CFZ-2A3-aE12	Specimen initial length 3.040 in.; bulk density 1.899 g cm^{-3}; expansion measured across grain.
12	380	Southern Research Institute	1964	L	294-3233	CFZ-2A3h-aE13	Specimen initial length 3.004 in.; bulk density 1.897 g cm^{-3}; expansion measured across grain.
13	380	Southern Research Institute	1964	L	3216-294	CFZ-2A3h-aE13	The above specimen; expansion measured with decreasing temperature; final length at 294 K 3.011 in.; zero-point correction of -0.18% determined by graphical extrapolation.
14	380	Southern Research Institute	1964	L	294-3216	CFZ-2A3h-aE14	Specimen initial length 3.004 in.; bulk density 1.897 g cm^{-3}; expansion measured across grain.
15	380	Southern Research Institute	1964	L	2255-294	CFZ-2A3h-aE14	The above specimen; expansion measured with decreasing temperature; final length at 294 K 3.012 in.; zero-point correction of -0.26% determined by graphical extrapolation.
16	380	Southern Research Institute	1964	L	294-3216	CFZ-2A3h-aE16	Specimen initial length 3.004 in.; bulk density 1.892 g cm^{-3}; expansion measured across grain.
17	380	Southern Research Institute	1964	L	2766-294	CFZ-2A3h-aE16	The above specimen; expansion measured with decreasing temperature; final length at 294 K 3.011 in.; zero-point correction of -0.22% determined by graphical extrapolation.

* Not shown in figure.

SPECIFICATION TABLE 14. THERMAL LINEAR EXPANSION OF GRADE CFZ GRAPHITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
18	381	Digesu, F.J. and Pears, C.D.	1965	L	293-3311		Specimen taken from interior of billet; expansion measured with grain.
19	381	Digesu, F.J. and Pears, C.D.	1965	L	293-3311		Similar to the above specimen; expansion measured across grain.
20	381	Digesu, F.J. and Pears, C.D.	1965	L	293-3311		Specimen taken from exterior area of billet; expansion measured with grain.
21	381	Digesu, F.J. and Pears, C.D.	1965	L	293-3311		Similar to the above specimen; expansion measured across grain.

DATA TABLE 14. THERMAL LINEAR EXPANSION OF GRADE CFZ GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
1273	0.265
1773	0.483
2275	0.749
2773	1.105
2980	1.257
CURVE 2	
1273	0.382
1771	0.604
2273	1.047
2773	1.534
2980	1.806
CURVE 3	
293	0.000
373	0.016
CURVE 4	
293	0.000*
773	0.119
1273	0.299
1773	0.523
2273	0.799
2673	1.066
3073	1.367
CURVE 5	
293	0.000*
373	0.021
CURVE 6	
293	0.000*
773	0.162
1273	0.357
1773	0.620
2273	0.959
2673	1.307
3073	1.712

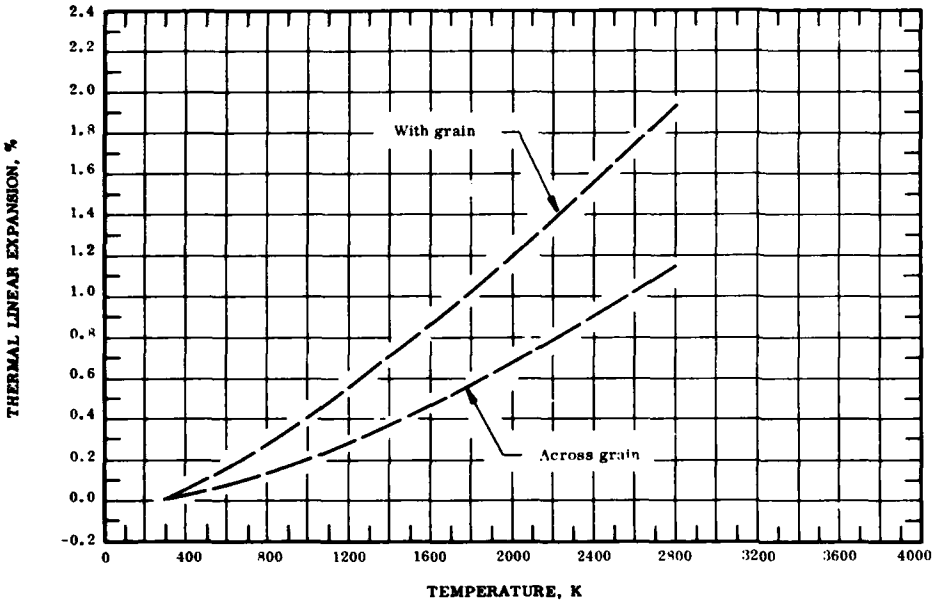
T	$\Delta L/L_0$
CURVE 7*	
293	0.00
373	0.02
CURVE 8*	
293	0.00
373	0.02
CURVE 9	
294	0.00*
1366	0.30
2200	0.63*
2825	1.06
3061	1.24
3311	1.36
CURVE 10	
2908	0.86
2603	0.63
1978	0.36
1630	0.25
1241	0.15
1125	0.11
294	0.00*
CURVE 11	
294	0.00*
538	0.06
1366	0.30*
2200	0.62
2769	1.00
3061	1.22
CURVE 12	
294	0.00*
1339	0.27
2200	0.58
2816	0.97
3005	1.12
3233	1.28

T	$\Delta L/L_0$
CURVE 13	
3216	1.09
2894	0.79
2539	0.59
1925	0.34
1678	0.26
1130	0.15
294	0.00*
CURVE 14	
294	0.00*
1339	0.29
2186	0.59
2719	0.97
3058	1.21
3216	1.30
CURVE 15	
2255	0.47
1691	0.28
294	0.00*
CURVE 16	
294	0.00*
1380	0.30
2205	0.63
2744	1.00
3041	1.22
3216	1.29
CURVE 17	
2766	0.75
2483	0.60
1916	0.35
1633	0.27
1094	0.13
294	0.00*
CURVE 18	
293	0.000*

T	$\Delta L/L_0$
CURVE 18 (cont.)	
1367	0.210
2200	0.485
2755	0.764
3033	0.915
3311	1.037
CURVE 19	
293	0.000*
1367	0.336
2200	0.698
2755	1.088
3033	1.317
3311	1.530
CURVE 20	
293	0.000*
1367	0.221*
2200	0.515
2755	0.794
3033	0.954
3311	1.077
CURVE 21	
293	0.000*
1367	0.316
2200	0.669
2755	1.050
3033	1.279
3311	1.460

* Not shown in figure.

FIGURE AND TABLE NO. 15R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF EXPERIMENTAL GRADE GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	2.2	0.000	4.8
400	0.025	2.5	0.054	5.2
600	0.079	2.9	0.163	5.8
800	0.143	3.4	0.284	6.3
1000	0.214	3.8	0.415	6.8
1200	0.294	4.2	0.555	7.3
1400	0.381	4.5	0.705	7.7
1600	0.475	4.8	0.862	8.1
1800	0.574	5.1	1.027	8.4
2000	0.679	5.4	1.198	8.7
2200	0.788	5.6	1.374	8.9
2400	0.902	5.8	1.555	9.1
2600	1.019	5.9	1.740	9.3
2800	1.139	6.0	1.927	9.4

REMARKS

The provisional values are considered accurate to within ± 10% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.053 + 1.429 \times 1.382 \times 10^{-4} T^2 - 1.326 \times 10^{-11} T^3$

With grain: $\Delta L/L_0 = -0.128 + 3.870 \times 10^{-4} T + 1.729 \times 10^{-4} T^2 - 1.750 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 10%.

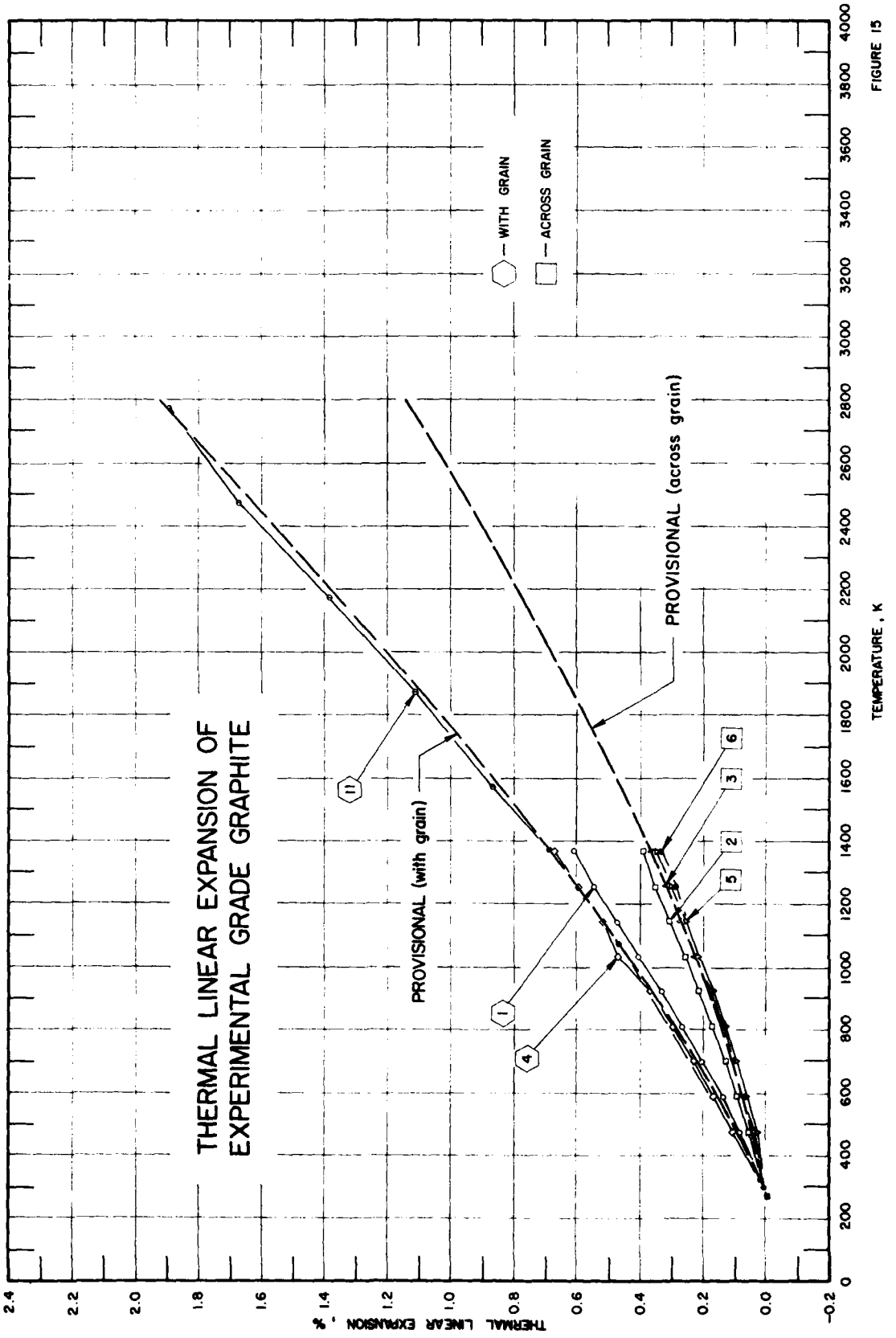

THERMAL LINEAR EXPANSION OF
EXPERIMENTAL GRADE GRAPHITE
— WITH GRAIN
— ACROSS GRAIN
PROVISIONAL (across grain)
PROVISIONAL (with grain)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000

FIGURE 15

SPECIFICATION TABLE 15. THERMAL LINEAR EXPANSION OF EXPERIMENTAL GRADE GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	368	Allen, R.D.	1959	L	300-1366	Block No. 1001 NT005 graphite	Specimen obtained from National Carbon Co.; molded; baked under pressure, not graphitized; expansion measured parallel to the grain direction.
2	368	Allen, R.D.	1959	L	300-1366	Block No. 1001 NT005 graphite	The above specimen except expansion measured perpendicular to the grain direction.
3	368	Allen, R.D.	1959	L	300-1366	Block No. 1001 NT005 graphite	Similar to the above specimen.
4	368	Allen, R.D.	1959	L	300-1366	Block No. 1002 NT005 graphite	Specimen obtained from National Carbon Co.; molded; baked under pressure, not graphitized; expansion measured parallel to grain direction.
5	368	Allen, R.D.	1959	L	300-1366	Block No. 1002 NT005 graphite	The above specimen except expansion measured perpendicular to the grain direction.
6	368	Allen, R.D.	1959	L	300-1366	Block No. 1002 NT005 graphite	Similar to the above specimen.
7*	372	Bradstreet, S.W., Atlas, L.M., Bortz, S.A., Lund, H.H., and Nakamura, H.H.	1960	L	273-2773	2-7	37 parts of Barrett No. 30 medium coal tar pitch (natural pitch binder) mixed with 100 parts of Texas-Lockport No. 90 calcined petroleum coke, molded, and graphitized; density 1.556 g cm^{-3}; volume (DC) resistance 0.0013686 ohm cm.
8*	372	Bradstreet, S.W., et al.	1960	L	273-2773	2-17	39 parts of Barrett No. 30 medium coal tar pitch (natural pitch binder) and 10 parts of thermax added to 90 parts of Texas-Lockport No. 90 calcined petroleum coke, mixed, molded and graphitized; density 1.642 g cm^{-3}; volume (DC) resistance 0.0014961 ohm cm.
9*	372	Bradstreet, S.W., et al.	1960	L	273-2773	8-6 FA + Pitch	20 parts of Barrett No. 30 medium coal tar pitch (natural pitch binder) mixed with 100 parts of Texas Lockport No. 90 calcined petroleum coke, molded, and graphitized at 3073 K (2800 C) for 4 hr, and then regraphitized at 3143 K (2870 C) for 2 hr; density 1.804 g cm^{-3}; volume (DC) resistance 0.001339 ohm cm.
10*	372	Bradstreet, S.W., et al.	1960	L	273-2773	2-23	20 parts of Quaker Oats commercial furfuryl alcohol mixed with 100 parts of Texas-Lockport No. 90 calcined petroleum coke, molded and graphitized at 2800 C for 4 hr, and then regraphitized at 2870 C for 2 hr; density 1.751 g cm^{-3}; volume (DC) resistance 0.0011638 ohm cm.
11	397	Epremian, E.	1964	L	325-2773		Expansion measured parallel to grain direction.

* Not shown in figure.

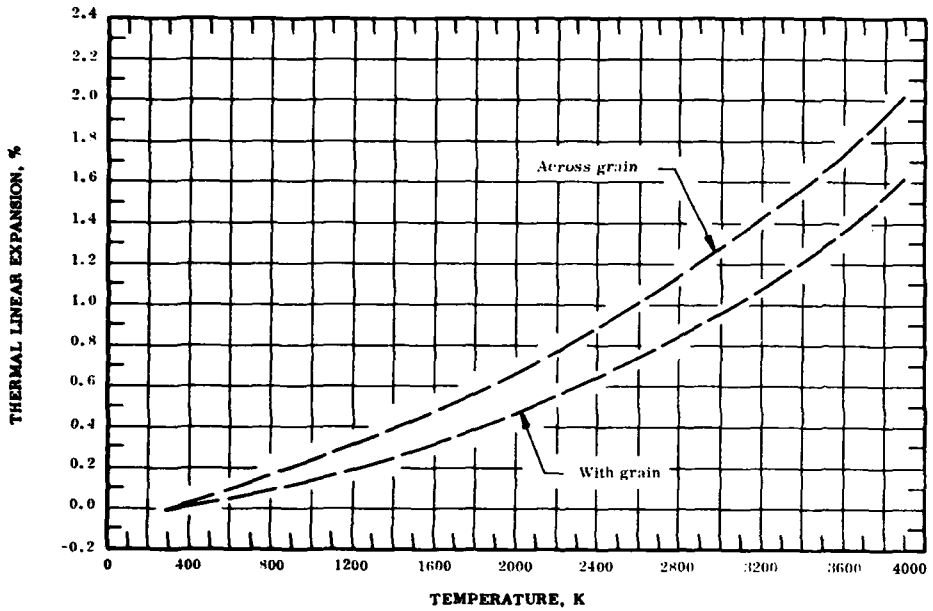
DATA TABLE 15. THERMAL LINEAR EXPANSION OF EXPERIMENTAL GRADE GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
300	0.003
477	0.080
588	0.138
700	0.204
810	0.267
922	0.333
1033	0.404
1144	0.473
1255	0.547
1366	0.609
CURVE 2	
300	0.002*
477	0.055
588	0.090
700	0.127
810	0.167
922	0.212
1033	0.257
1144	0.302
1255	0.352
1366	0.390
CURVE 3	
300	0.001*
477	0.037
588	0.067
700	0.102
810	0.137
922	0.179
1033	0.225
1144	0.271
1255	0.319
1366	0.365
CURVE 4	
300	0.004*
477	0.102
588	0.164
700	0.229
810	0.295
922	0.367
1033	0.445
1144	0.516
1255	0.594
1366	0.667
CURVE 5	
300	0.001*
477	0.027
588	0.061
700	0.095
810	0.131
922	0.173
1033	0.210
1144	0.254
1255	0.300
1366	0.344
CURVE 6	
300	0.001*
477	0.035*
588	0.058*
700	0.091*
810	0.130*
922	0.168*
1033	0.208*
1144	0.251*
1255	0.295
1366	0.338
CURVE 7*	
273	-0.009
1773	0.691
2773	1.290
CURVE 8*	
273	-0.010
1773	0.713
2773	1.382
CURVE 9*	
273	-0.008
1773	0.616
2773	1.189
CURVE 10*	
273	-0.007
1773	0.667
2773	1.281
CURVE 11	
325	0.019
1075	0.463
1371	0.686
1571	0.868
1874	1.111
2174	1.381
2476	1.675
2773	1.893

* Not shown in figure.

FIGURE AND TABLE NO. 16R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE GBE GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	2.8	0.000	1.9
400	0.031	2.9	0.020	2.0
600	0.091	3.1	0.061	2.1
800	0.155	3.3	0.105	2.3
1000	0.224	3.6	0.153	2.5
1200	0.298	3.8	0.206	2.7
1400	0.378	4.1	0.263	3.0
1600	0.463	4.4	0.326	3.3
1800	0.555	4.7	0.395	3.6
2000	0.653	5.1	0.471	3.9
2200	0.759	5.5	0.553	4.3
2400	0.872	5.9	0.643	4.7
2600	0.993	6.3	0.741	5.1
2800	1.123	6.7	0.848	5.6
3000	1.262	7.2	0.963	6.0
3200	1.410	7.6	1.089	6.5
3400	1.568	8.1	1.224	7.0
3600	1.736	8.7	1.369	7.6
3800	1.915	9.2	1.526	8.1
3900	2.008	9.5	1.615	8.4

REMARKS

The provisional values are considered accurate to within ±10% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.079 + 2.591 \times 10^{-4}\ T + 3.542 \times 10^{-8}\ T^2 + 9.074 \times 10^{-12}\ T^3$

With grain: $\Delta L/L_0 = -0.052 + 1.706 \times 10^{-4}\ T + 2.434 \times 10^{-8}\ T^2 + 1.055 \times 10^{-11}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

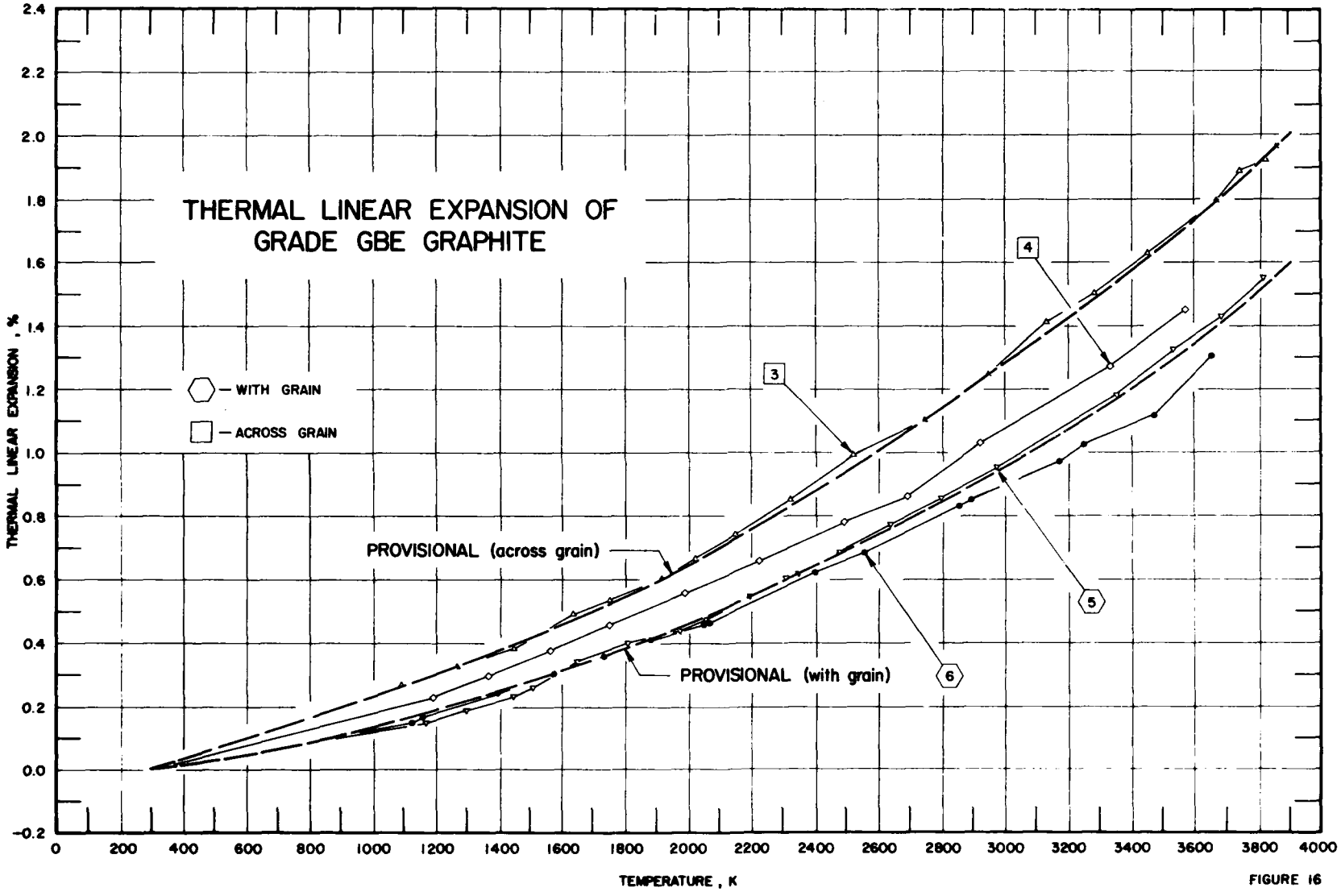

THERMAL LINEAR EXPANSION OF
GRADE GBE GRAPHITE
WITH GRAIN
ACROSS GRAIN
PROVISIONAL (across grain)
PROVISIONAL (with grain)
3
4
5
6
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000

FIGURE 16

SPECIFICATION TABLE 16. THERMAL LINEAR EXPANSION OF GRADE GBE GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	382	Fieldhouse, I. B., Hedge, J. C., Lang, J. I., Takata, A. N. and Waterman, T. E.	1956	T	297-1864		Rod specimen; data average of three separate runs; zero-point correction of ±0.000% determined by graphical extrapolation.
2*	382	Fieldhouse, I. B., et al.	1956	T	1636-297		The above specimen; expansion measured with decreasing temperature; zero-point correction of ±0.000% determined by graphical extrapolation.
3	383	Rasor, N. S. and McClelland, J. D.	1957	T	293-3845		Extruded rod specimen, 0.375 in. dia, 11 in. long; obtained from National Carbon Co.; very fine grained; expansion measured perpendicular to extrusion axis.
4	383	Rasor, N. S. and McClelland, J. D.	1957	T	3570-293		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.256%.
5	383	Rasor, N. S. and McClelland, J. D.	1957	T	293-3815		Similar to the above specimen; expansion measured parallel to extrusion axis with increasing temperature.
6	383	Rasor, N. S. and McClelland, J. D.	1957	T	3656-293		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.117%.

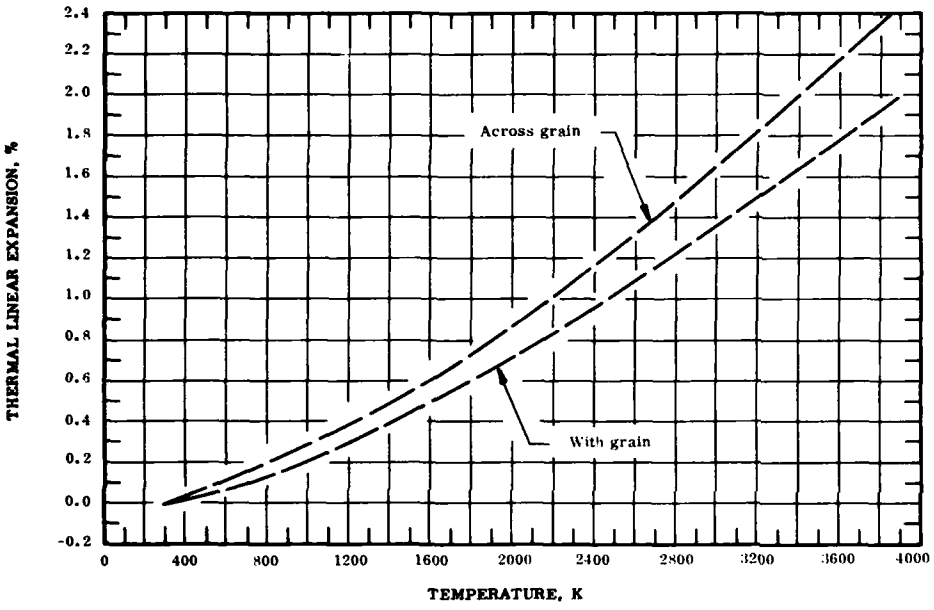
DATA TABLE 16. THERMAL LINEAR EXPANSION OF GRADE GBE GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*		CURVE 3 (cont.)		CURVE 4		CURVE 5 (cont.)		CURVE 6	
297	0.000	1636	0.383	1262	0.333	3570	1.454	1442	0.239	3656	1.305
453	0.018	1558	0.354	1443	0.385	3333	1.275	1512	0.267	3471	1.122
488	0.029	1455	0.308	1637	0.496	2926	1.036	1644	0.349	3245	1.027
599	0.044	1348	0.270	1747	0.542	2693	0.861	1807	0.405	3168	0.973
685	0.060	1308	0.266	1914	0.605	2490	0.782	1969	0.441	2888	0.849
728	0.073	860	0.112	2010	0.673	2223	0.661	2054	0.479	2854	0.835
811	0.089	808	0.092	2148	0.747	1988	0.564	2195	0.556	2554	0.690
896	0.120	752	0.080	2322	0.857	1749	0.462	2310	0.609	2395	0.627
1047	0.164	695	0.064	2524	0.997	1560	0.381	2348	0.621	2065	0.473
1211	0.224	658	0.054	2747	1.112	1363	0.303	2478	0.693	2051	0.461
1230	0.230	640	0.052	2952	1.246	1187	0.237	2639	0.777	1877	0.419
1369	0.289	505	0.030	3138	1.414	293	0.000*	2793	0.858	1737	0.365
1405	0.305	297	0.000	3281	1.507			2969	0.953	1568	0.310
1494	0.328			3446	1.633	CURVE 5		3358	1.188	1390	0.244
1573	0.358	CURVE 3		3663	1.798			3537	1.328	1156	0.173
1697	0.402			3743	1.891	293	0.000*	3685	1.429	1122	0.153
1735	0.444	293	0.000*	3810	1.925	1163	0.157	3815	1.554	293	0.000*
1864	0.470	1089	0.272	3845	1.969	1299	0.196				

* Not shown in figure.

FIGURE AND TABLE NO. 17R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE GBH GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	3.0	0.000	2.3
400	0.034	3.3	0.026	2.5
600	0.105	3.9	0.082	3.0
800	0.188	4.4	0.147	3.5
1000	0.280	4.9	0.222	4.0
1200	0.383	5.4	0.306	4.4
1400	0.494	5.8	0.398	4.8
1600	0.615	6.2	0.497	5.1
1800	0.743	6.6	0.603	5.5
2000	0.878	7.0	0.715	5.8
2200	1.021	7.3	0.833	6.0
2400	1.169	7.6	0.957	6.3
2600	1.324	7.8	1.085	6.5
2800	1.483	8.1	1.217	6.7
3000	1.647	8.3	1.353	6.9
3200	1.815	8.5	1.492	7.0
3400	1.986	8.6	1.634	7.1
3600	2.160	8.8	1.777	7.2
3800	2.337	8.9	1.921	7.3
3900	*2.425*	*8.9*	*1.994*	*7.3*

REMARKS

The provisional values are considered accurate to within ±10% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.074 + 2.091 \times 10^{-4} T + 1.578 \times 10^{-7} T^2 - 1.206 \times 10^{-11} T^3$

With grain: $\Delta L/L_0 = -0.054 + 1.458 \times 10^{-4} T + 1.429 \times 10^{-7} T^2 - 1.170 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

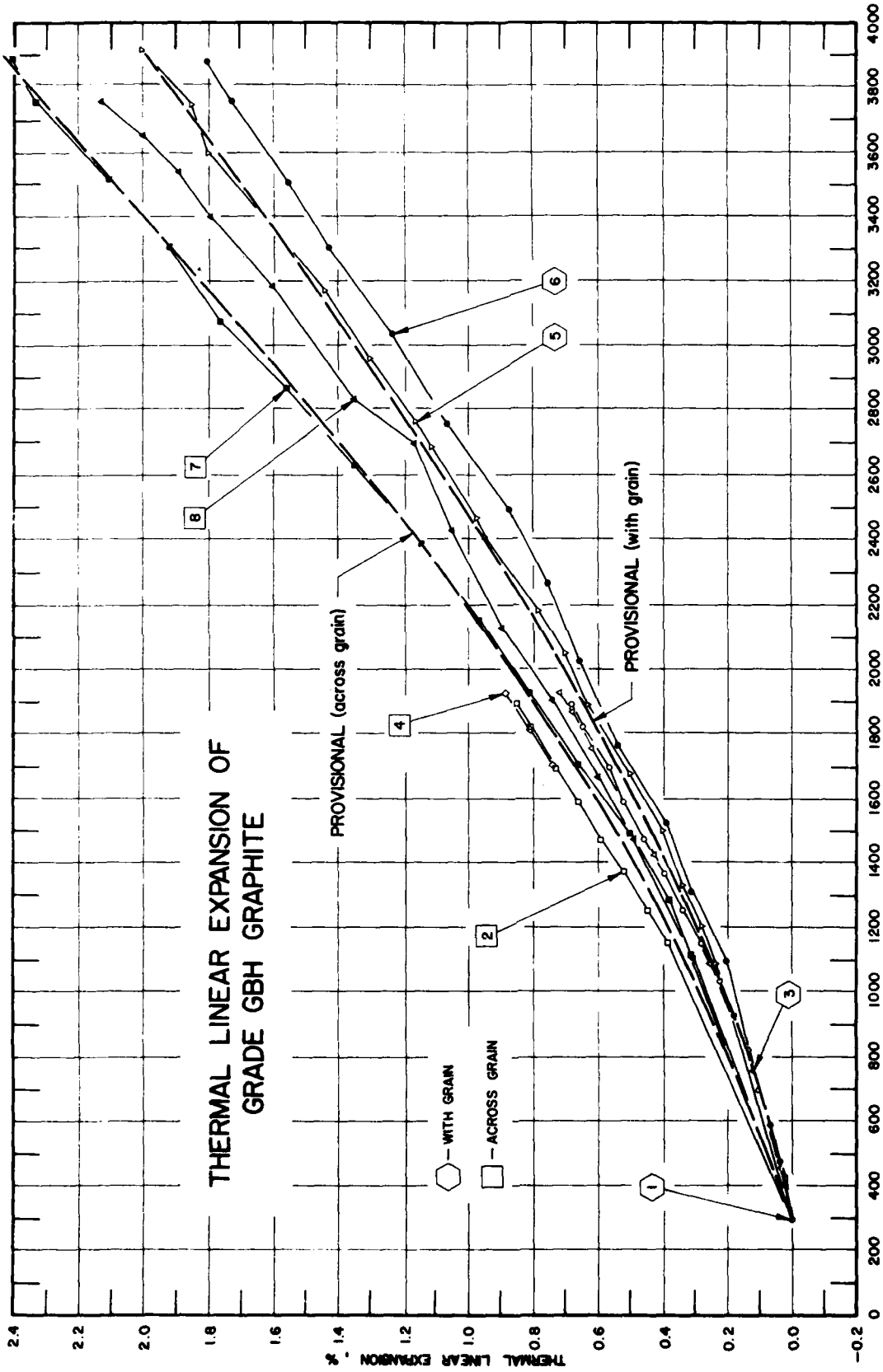

THERMAL LINEAR EXPANSION OF
GRADE GBH GRAPHITE
PROVISIONAL (across grain)
PROVISIONAL (with grain)
WITH GRAIN
ACROSS GRAIN
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
1
2
3
4
5
6
7
8

FIGURE 17

SPECIFICATION TABLE 17. THERMAL LINEAR EXPANSION OF GRADE GBH GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	384	Lucks, C. F., Deem, H. W. and Wood, W. D.	1960	L	293-1866		*Specimen obtained from National Carbon Co.; 0.375 in. diameter, 3 in. long; molded; heated at rate less than 3 C per min; density 0.0632 lb. in.$^{-3}$ at 297 K; expansion measured perpendicular to direction of molding.*
2	384	Lucks, C. F., et al.	1960	L	293-1866		The above specimen except expansion measured parallel to direction of molding.
3	385	Lucks, C. F. and Deem, H. W.	1956	L	293-1922		Similar to the above specimen; expansion measured perpendicular to direction of molding.
4	386	Lucks, C. F. and Deem, H. W.	1956	L	293-1922		The above specimen; expansion measured parallel to direction of molding.
5	383	Rasor, N. S. and McClelland, J. D.	1957	T	293-3914		Molded specimen obtained from National Carbon Co.; very fine grained; expansion measured perpendicular to direction of molding pressure with increasing temperature.
6	383	Rasor, N. S. and McClelland, J. D.	1957	T	3875-293		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.151%.
7	383	Rasor, N. S. and McClelland, J. D.	1957	T	293-3881		The above specimen; expansion measured parallel to direction of molding pressure with increasing temperature.
8	383	Rasor, N. S. and McClelland, J. D.	1957	T	3760-293		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.111%.

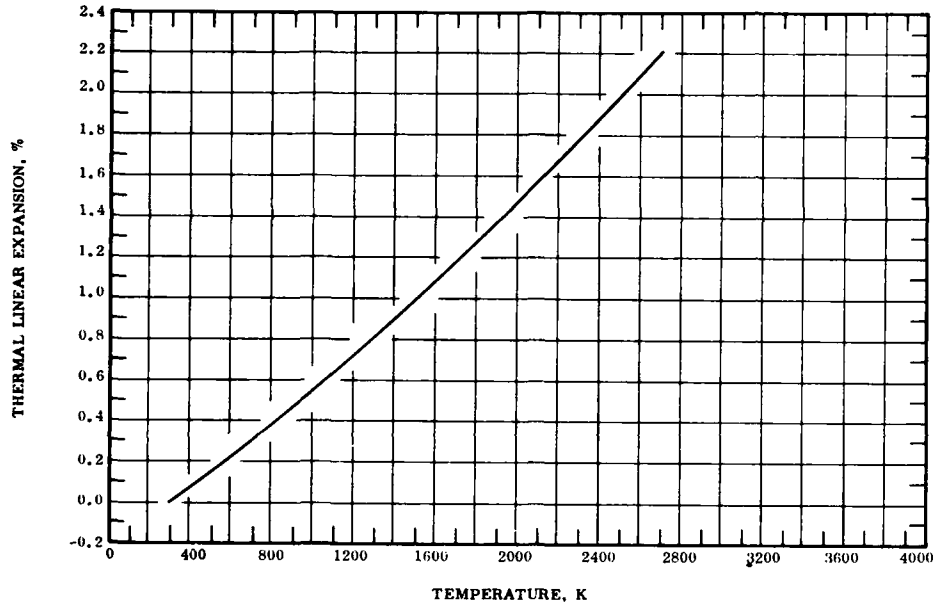
DATA TABLE 17. THERMAL LINEAR EXPANSION OF GRADE GBH GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
477	0.040
588	0.071
699	0.106
810	0.144
922	0.187
1033	0.234
1144	0.288
1255	0.343
1366	0.402
1477	0.465
1588	0.527
1699	0.590
1810	0.653
1866	0.685
CURVE 2	
293	0.000*
1144	0.392
1255	0.457
1366	0.526
1477	0.597
1588	0.667
1699	0.739
1810	0.814
1866	0.852
CURVE 3	
293	0.000*
422	0.023
589	0.071*
755	0.125
922	0.187*
1089	0.260
1255	0.344*
1422	0.433
1589	0.526*
1755	0.621
1866	0.685
1922	0.720
CURVE 4	
293	0.000*
1144	0.392*
CURVE 4 (cont.)	
1255	0.458*
1366	0.526*
1478	0.596*
1589	0.666*
1700	0.740
1811	0.814
1922	0.887
CURVE 5	
293	0.000*
1087	0.242
1202	0.284
1335	0.345
1502	0.409
1676	0.506
1890	0.620
2049	0.706
2185	0.788
2407	0.950
2465	0.972
2685	1.111
2765	1.164
2960	1.302
3170	1.442
3600	1.801
3756	1.854
3914	2.007
CURVE 6	
3875	1.807
3760	1.731
3505	1.553
3301	1.430
3038	1.240
2757	1.065
2497	0.875
2266	0.759
2025	0.663
1763	0.542
1526	0.396
1318	0.317
1091	0.209
293	0.000*
CURVE 7	
293	0.000*
1111	0.319
1287	0.386
1492	0.502
1704	0.668
1925	0.810
2158	0.966
2385	1.148
2627	1.349
2865	1.560
3076	1.762
3301	1.922
3517	2.103
3759	2.332
3881	2.404
CURVE 8	
3760	2.138*
3650	2.001
3540	1.894
3399	1.798
3181	1.606
2828	1.353
2699	1.177
2424	1.051
2129	0.892
1902	0.743
1664	0.602
1477	0.496
1102	0.312
293	0.000

* Not shown in figure.

FIGURE AND TABLE NO. 18R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF POCO AXM-5Q GRAPHITE



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	7.1
400	0.078	7.3
600	0.228	7.7
800	0.386	8.1
1000	0.551	8.4
1200	0.722	8.7
1400	0.900	9.1
1600	1.085	9.4
1800	1.276	9.7
2000	1.474	10.0
2200	1.677	10.3
2400	1.886	10.6
2600	2.101	10.9
2700	2.211	11.0

REMARKS

The recommended values are based on the data for the isotropic samples and are considered accurate to within ±5%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.201 + 6.595 \times 10^{-4} T + 9.593 \times 10^{-8} T^2 - 3.427 \times 10^{12} T^{-3}$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±7%.

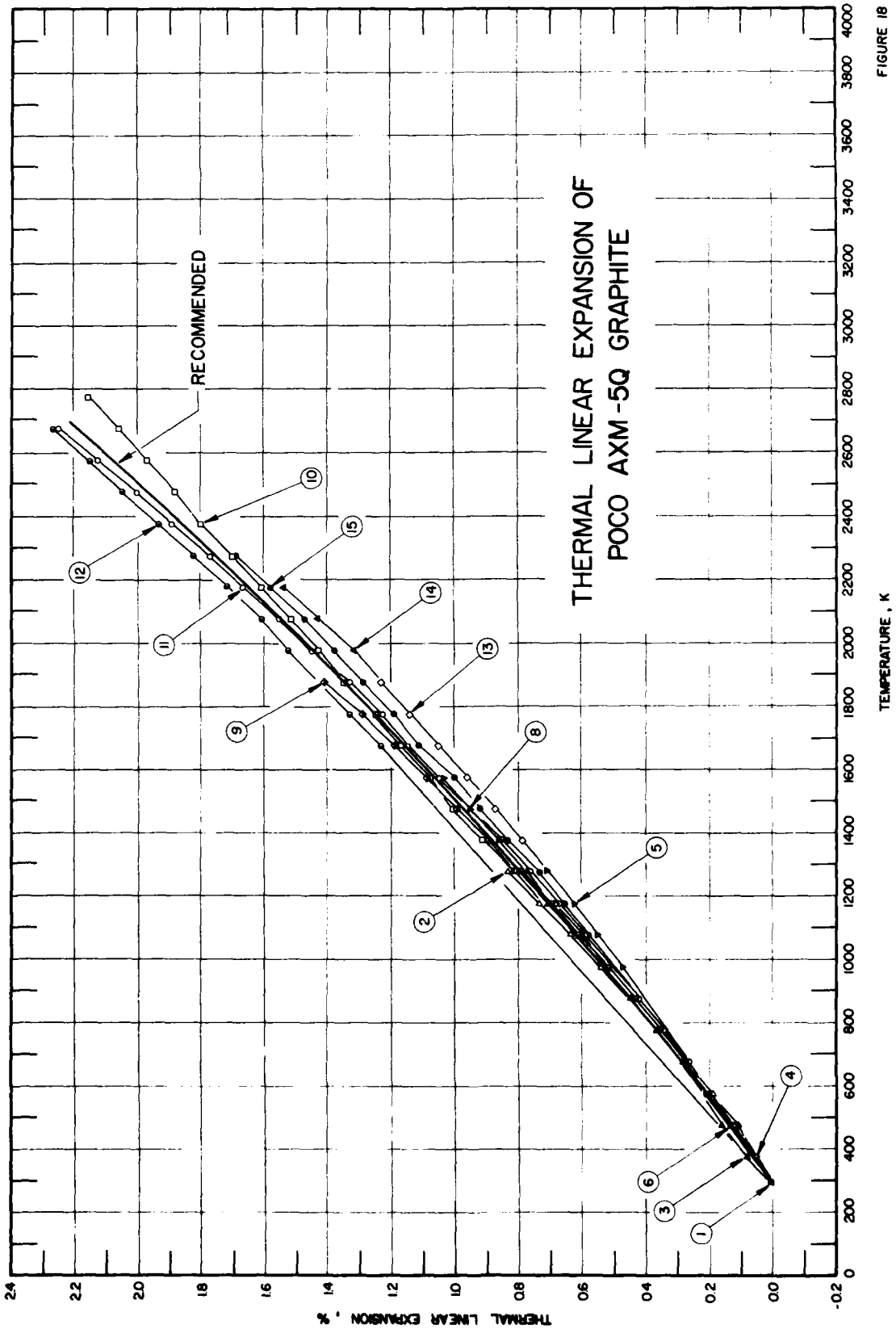

THERMAL LINEAR EXPANSION OF
POCO AXM-5Q GRAPHITE
RECOMMENDED
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
1
2
3
4
5
6
8
9
10
11
12
13
14
15

FIGURE 18

SPECIFICATION TABLE 18. THERMAL LINEAR EXPANSION OF POCO AXM-5Q GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen *Designation*	Composition (weight percent), Specifications, and Remarks
1	638	Fitzer, E.	1971	L	293-1273		POCO-graphite AXM 5Q; particle size 0.001 in.; manufacturing method claimed to be proprietary; density 1.70-1.78 g cm^{-3}; porosity 21%; process temperature 2773 K; expansion measured by participant No. 6.
2	638	Fitzer, E.	1971	L	293-1273		Similar to the above specimen; expansion measured by participant No. 8.
3	638	Fitzer, E.	1971	L	293-1273		Similar to the above specimen; expansion measured by participant No. 16.
4	638	Fitzer, E.	1971	L	293-1173		Similar to the above specimen; expansion measured by participant No. 29.
5	638	Fitzer, E.	1971	L	293-1273		Similar to the above specimen; expansion measured by participant No. 32.
6	638	Fitzer, E.	1971	L	293-1273		Similar to the above specimen; expansion measured by participant No. 45.
7*	638	Fitzer, E.	1971	L	293-1273		Similar to the above specimen; expansion measured by participant No. 46.
8	644	Fitzer, E.	1972	L	293-1573		AXM-5Q graphite distributed by AGARD; produced by POCO Inc., Garland, Texas; ultra-fine-grain graphite manufacutred by a proprietary process; bulk density 1.70-1.78 g/cc; without showing any significant bulk anisotropy in physical and mechanical properties; expansion measured by participant No. 5.
9	644	Fitzer, E.	1972	L	293-1873		Similar to the above specimen; expansion measured by participant No. 8.
10	644	Fitzer, E.	1972	L	293-2773		Similar to the above specimen; expansion measured by participant No. 16.
11	644	Fitzer, E.	1972	O	293-2673		Similar to the above specimen; expansion measured by participant No. 46.
12	644	Fitzer, E.	1972	O	293-2673		Similar to the above specimen except not distributed by AGARD; expansion measured by participant No. 42.
13	644	Fitzer, E.	1972	T	293-1873		Similar to the above specimen except not distributed by AGARD; heat treated at 3273 K for 1 hr; expansion measured by participant No. 32.
14	644	Fitzer, E.	1972	T	293-2173		Similar to the above specimen; expansion measured by participant No. 48.
15	644	Fitzer, E.	1972	T	293-2273		Similar to the above specimen; expansion measured by participant No. 53.

* Not shown in figure.

DATA TABLE 18. THERMAL LINEAR EXPANSION OF POCO AXM-5Q GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
293	0.000
573	0.203
673	0.277
773	0.355
873	0.436
973	0.519
1073	0.607
1173	0.697
1273	0.793

CURVE 2

T	$\Delta L/L_0$
293	0.000*
573	0.191
673	0.271*
773	0.356*
873	0.445
973	0.540
1073	0.635
1173	0.737
1273	0.836

CURVE 3

T	$\Delta L/L_0$
293	0.000*
373	0.080
473	0.160
573	0.200*
673	0.280*
773	0.360
873	0.445*
973	0.530
1073	0.600
1173	0.710
1273	0.770

CURVE 4

T	$\Delta L/L_0$
293	0.000*
373	0.050
473	0.120
573	0.190*
673	0.270*
773	0.355*
873	0.445*
973	0.525*
1073	0.600*
1173	0.685

CURVE 5

T	$\Delta L/L_0$
293	0.000*
973	0.467
1073	0.544
1173	0.620
1273	0.705

CURVE 6

T	$\Delta L/L_0$
293	0.000*
373	0.057*
473	0.128
573	0.203*
673	0.282*
773	0.362*
873	0.447*
973	0.534*
1073	0.623
1173	0.717*
1273	0.818

CURVE 7*

T	$\Delta L/L_0$
293	0.000
373	0.056
473	0.127
573	0.202
673	0.279
773	0.358
873	0.440
973	0.524
1073	0.610
1173	0.698
1273	0.788

CURVE 8

T	$\Delta L/L_0$
293	0.000*
373	0.050*
473	0.120*
573	0.195*
673	0.275*
773	0.360*
873	0.440*
973	0.520*
1073	0.605*
1173	0.685*
1273	0.775*
1373	0.860

CURVE 8 (cont.)

T	$\Delta L/L_0$
1473	0.945
1573	1.035

CURVE 9

T	$\Delta L/L_0$
293	0.000*
473	0.115
573	0.194*
673	0.271*
773	0.357*
873	0.442*
973	0.528*
1073	0.619*
1173	0.705*
1273	0.803*
1373	0.895
1473	0.993
1573	1.088
1673	1.190
1773	1.291
1873	1.410

CURVE 10

T	$\Delta L/L_0$
293	0.000*
473	0.130*
573	0.200*
673	0.275*
773	0.355*
873	0.435*
973	0.515*
1073	0.600*
1173	0.685*
1273	0.765*
1373	0.910
1473	1.000
1573	1.080
1673	1.170
1773	1.250
1873	1.350
1973	1.430
2073	1.520
2173	1.610
2273	1.700
2373	1.800
2473	1.880
2573	1.970
2673	2.060

CURVE 10 (cont.)

T	$\Delta L/L_0$
2773	2.160

CURVE 11

T	$\Delta L/L_0$
293	0.000*
373	0.051*
473	0.118
573	0.189
673	0.263
773	0.340
873	0.421
973	0.504
1073	0.589
1173	0.677
1273	0.767
1373	0.859
1473	0.953*
1573	1.049
1673	1.147
1773	1.247
1873	1.349
1973	1.453
2073	1.559
2173	1.668
2273	1.770
2373	1.891
2473	2.006
2573	2.124
2673	2.245

CURVE 12

T	$\Delta L/L_0$
293	0.000*
1673	1.234
1773	1.330
1873	1.413*
1973	1.522
2073	1.613
2173	1.720
2273	1.826
2373	1.933
2473	2.047
2573	2.152
2673	2.261

CURVE 13

T	$\Delta L/L_0$
293	0.000*
973	0.467*
1073	0.544*
1173	0.620*
1273	0.705*
1373	0.788
1473	0.875
1573	0.960
1673	1.050
1773	1.140
1873	1.233

CURVE 14

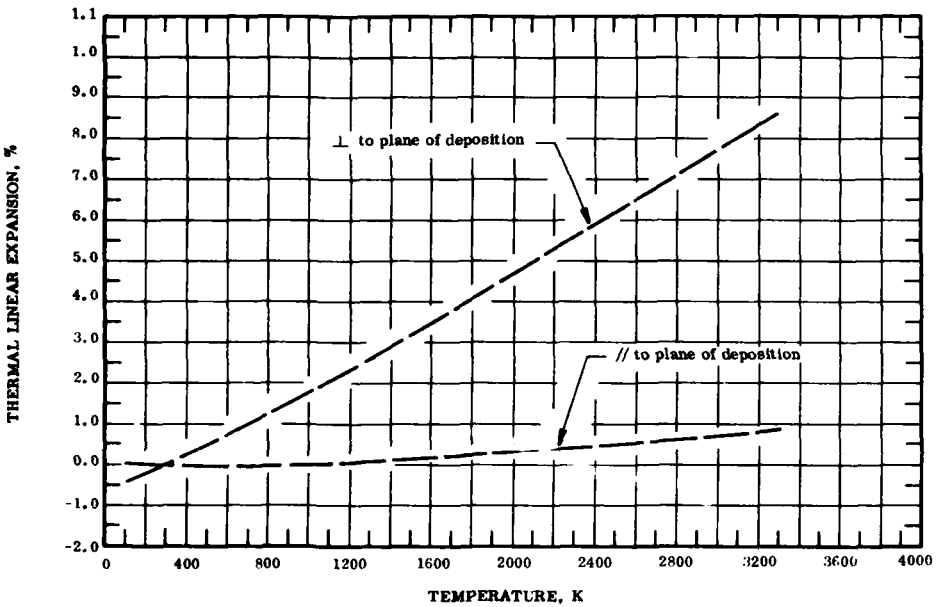
T	$\Delta L/L_0$
293	0.000*
1773	1.135
1873	1.230*
1973	1.320
2073	1.430
2173	1.540

CURVE 15

T	$\Delta L/L_0$
293	0.000*
973	0.500*
1073	0.580
1173	0.650
1273	0.730
1373	0.830
1473	0.920
1573	1.000
1673	1.110
1773	1.190
1873	1.290
1973	1.380
2073	1.476
2173	1.580
2273	1.690

* Not shown in figure.

FIGURE AND TABLE NO. 19R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF PYROLYTIC GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	⊥ Plane of Deposition		// Plane of Deposition	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
100	-0.434		0.023	
200	-0.212		0.012	
293	0.000	23.1	0.000	-0.6
400	0.251	23.8	-0.007	-0.3
600	0.738	24.9	-0.001	0.3
800	1.245	25.9	-0.010	0.8
1000	1.772	26.8	0.033	1.4
1200	2.316	27.6	0.065	1.9
1400	2.875	28.3	0.110	2.3
1600	3.447	28.9	0.158	2.7
1800	4.030	29.4	0.216	3.1
2000	4.621	29.8	0.281	3.4
2200	5.220	30.0	0.353	3.7
2400	5.822	30.2	0.430	4.0
2600	6.427	30.3	0.510	4.2
2800	7.033	30.3	0.600	4.4
3000	7.637	30.3	0.690	4.6
3200	8.238	30.3	0.783	4.7
3300	8.536	30.4	0.830	4.7

REMARKS

The provisional values are considered accurate to within ± 10% and are represented approximately by the following equations:

⊥ plane of deposition: $\Delta L/L_0 = -0.650 + 2.122 \times 10^{-3}\ T + 3.431 \times 10^{-7}\ T^2 - 4.327 \times 10^{-11}\ T^3$ (293-3300 K)

// plane of deposition: $\Delta L/L_0 = 0.038 - 1.623 \times 10^{-4}\ T + 1.731 \times 10^{-7}\ T^2 - 1.547 \times 10^{-11}\ T^3$ (293-3300 K)

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 10%.

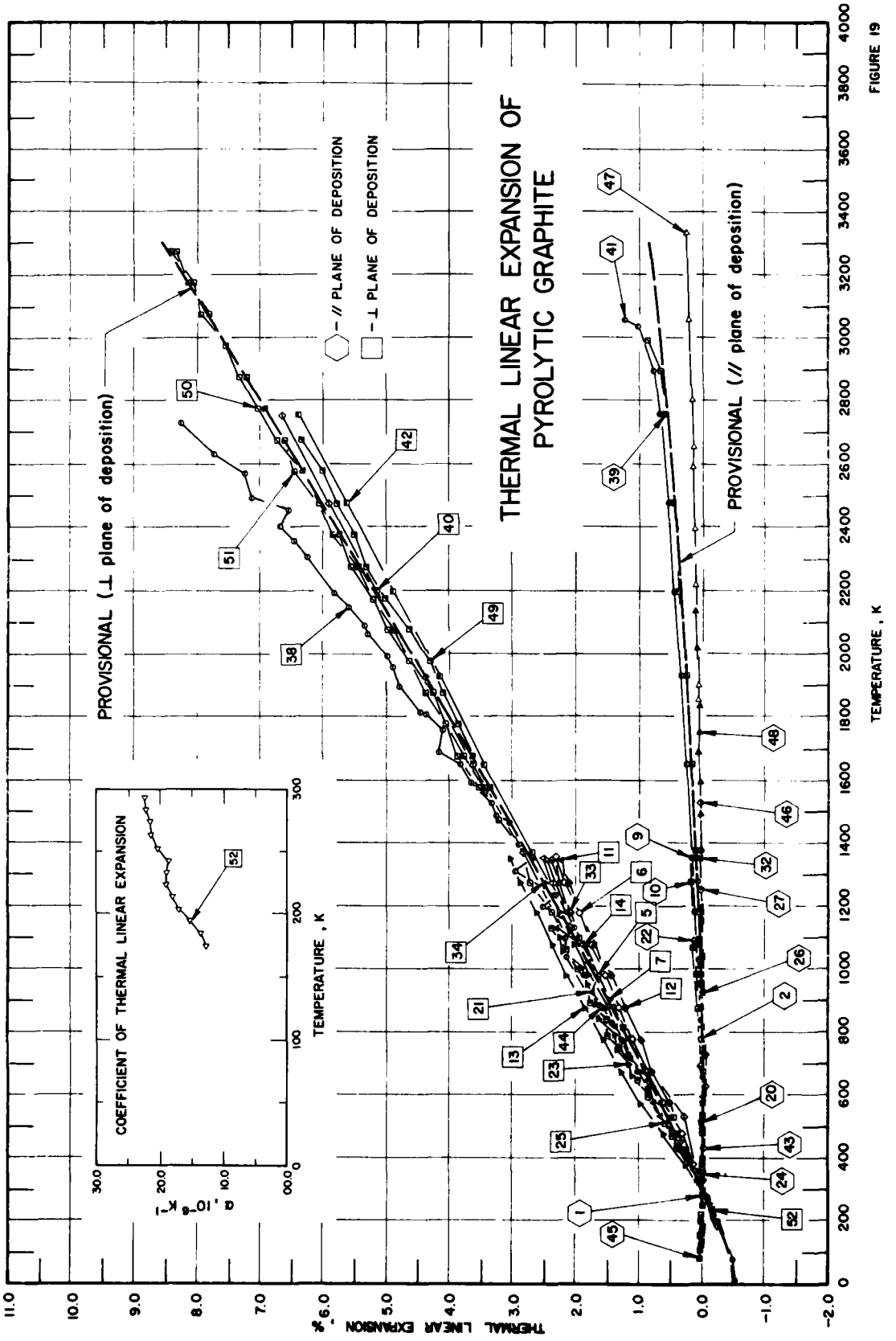

THERMAL LINEAR EXPANSION OF PYROLYTIC GRAPHITE
PROVISIONAL (⊥ plane of deposition)
PROVISIONAL (// plane of deposition)
// PLANE OF DEPOSITION
⊥ PLANE OF DEPOSITION
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K

FIGURE 19

SPECIFICATION TABLE 19. THERMAL LINEAR EXPANSION OF PYROLYTIC GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	3	Steele, S.R., Pappis, J., Schilling, H., and Hagan, L.	1967		273, 1273		Specimen deposited from the vapor at 1973-2373 K.
2	410	Raytheon Company	1963		373-1348		Specimen deposited at 2123 K; expansion measured parallel to deposition plane; zero-point correction of 0.0011% determined by graphical extrapolation.
3*	410	Raytheon Company	1963		373-1351		Specimen deposited at 2273 K; expansion measured parallel to deposition plane; zero-point correction of 0.0005% determined by graphical extrapolation.
4*	410	Raytheon Company	1963		373-1354		Specimen deposited at 2373 K; expansion measured parallel to deposition plane; density 2.20 g cm^{-3}; zero-point correction of 0.001% determined by graphical extrapolation.
5	410	Raytheon Company	1963		373-1349		Specimen deposited at 2123 K; expansion measured perpendicular to deposition plane; zero-point correction of -0.05% determined by graphical extrapolation.
6	410	Raytheon Company	1963		373-1351		Specimen deposited at 2273 K; expansion measured perpendicular to deposition plane; zero-point correction of -0.04% determined by graphical extrapolation.
7	410	Raytheon Company	1963		373-1347		Specimen deposited at 2373 K; expansion measured perpendicular to deposition plane; density 2.20 g cm^{-3}; zero-point correction of -0.06% determined by graphical extrapolation.
8*	410	Raytheon Company	1963		373-1349		99.65 pyrographite, 0.35 boron; specimen deposited at 2273 K; expansion measured parallel to deposition plane; zero-point correction of 0.002% determined by graphical extrapolation.
9	410	Raytheon Company	1963		573-1349		98.8 pyrographite, 1.2 boron; specimen deposited at 2273 K; expansion measured parallel to deposition plane; zero-point correction of 0.001% determined by graphical extrapolation.
10	410	Raytheon Company	1963		373-1349		98.5 pyrographite, 1.5 boron; specimen deposited at 2273 K; expansion measured parallel to deposition plane; zero-point correction of 0.001% determined by graphical extrapolation.
11	410	Raytheon Company	1963		373-1344		99.99 pyrographite, 0.01 boron; specimen deposited at 2273 K; density 2.20 g cm^{-3}; expansion measured perpendicular to deposition plane; zero-point correction of -0.04% determined by graphical extrapolation.
12	410	Raytheon Company	1963		373-1346		99.9 pyrographite, 0.1 boron; specimen deposited at 2273 K; density 2.20 g cm^{-3}; expansion measured perpendicular to deposition plane; zero-point correction of -0.04% determined by graphical extrapolation.
13	410	Raytheon Company	1963		373-1346		99.65 pyrographite, 0.35 boron; specimen deposited at 2273 K; density 2.20 g cm^{-3}; expansion measured perpendicular to deposition plane; zero-point correction of -0.07% determined by graphical extrapolation.
14	410	Raytheon Company	1963		373-1345		98.8 pyrographite, 1.2 boron; specimen deposited at 2273 K; density 2.20 g cm^{-3}; expansion measured perpendicular to deposition plane; zero-point correction of -0.05% determined by graphical extrapoltion.
15*	410	Raytheon Company	1963		373-1348		99.9 pyrographite, 0.1 boron; specimen deposited at 2273 K; density 2.20 g cm^{-3}; expansion measured parallel to deposition plane; zero-point correction of 0.001% determined by graphical extrapolation.

*Not shown in figure.

SPECIFICATION TABLE 19. THERMAL LINEAR EXPANSION OF PYROLYTIC GRAPHITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
16*	410	Raytheon Company	1963		373-1353		98.5 pyrographite, 1.5 boron; specimen deposited at 2123 K; density 2.18 g cm^{-3}; expansion measured parallel to deposition plane; zero-point correction of -0.002% determined by graphical extrapolation.
17*	410	Raytheon Company	1963		373-1347		Specimen deposited at 2123 K; density 2.18 g cm^{-3}; expansion measured parallel to deposition plane; zero-point correction of 0.002% determined by graphical extrapolation.
18*	410	Raytheon Company	1963		373-1348		98.6 pyrographite, 1.4 boron; specimen deposited at 2123 K; density 2.18 g cm^{-3}; expansion measured perpendicular to deposition plane; zero-point correction of -0.03% determined by graphical extrapolation.
19*	410	Raytheon Company	1963		373-1348		Specimen deposited at 2123 K; density 2.18 g cm^{-3}; expansion measured perpendicular to deposition plane; zero-point correction of -0.03% determined by graphical extrapolation.
20	411	Knibbs, R.H. and Mason, I.B.	1964	L	293-1061		Specimen supplied by High Temperature Materials, Inc.; manufactured at 2423 K; expansion measured parallel to plane of deposition; limiting angular displacement of crystalline c-axis from normal to plane of deposition 41°.
21	411	Knibbs, R.H. and Mason, I.B.	1964	L	293-1123		The above specimen except expansion measured perpendicular to plane of deposition.
22	411	Knibbs, R.H. and Mason, I.B.	1964	L	293-1081		Specimen supplied by High Temperature Materials, Inc.; manufactured at 2423 K and heat-treated at 2973 K for 0.5 hr in argon atmosphere; expansion measured parallel to plane of deposition; limiting angular displacement of crystallite c-axis from normal to plane of deposition 30°.
23	411	Knibbs, R.H. and Mason, I.B.	1964	L	293-1099		The above specimen except expansion measured perpendicular to plane of deposition.
24	411	Knibbs, R.H. and Mason, I.B.	1964	L	293-1025		Specimen supplied by High Temperature Materials, Inc.; manufactured at 2423 K and heat-treated to 3173 K for 0.5 hr in argon atmosphere; expansion measured parallel to plane of deposition; limiting angular displacement of crystallite c-axis from normal to plane of deposition 8°.
25	411	Knibbs, R.H. and Mason, I.B.	1964	L	293-1125		The above specimen except expansion measured perpendicular to plane of deposition.
26	412	Garber, A.M., Nolan, E.J., and Scala, S.M.	1963		273-1189		Highly regenerative continuously nucleated; specimen deposited from hydrocarbon gas to temperature ranging up to 2778 K in vacuum furnace; expansion measured parallel to a-direction of the hexagonal basal plane (a-b-plane); zero-point correction of 0.0000% determined by graphical interpolation.
27	412	Garber, A.M., et al.	1963		273-1244		Specimen surface nucleated; deposited from hydrocarbon gas to temperature ranging up to 2778 K in vacuum furnace; expansion measured parallel to a-direction of the hexagonal basal plane (a-b-plane); zero-point correction of 0.0000% determined by graphical interpolation.
28*	413	Richardson, J.H. and Zehms, E.H.	1963	T	1023-3206		Specimen prepared from a 0.125 in. thick central zone of a 0.75 in. thick block; fabricated by the High Temperature Materials Co., Boston, Mass., which formed at 2423 K with deposition time of 200 hrs; expansion measured parallel to a-axis of the basal plane with average heating rate 10 C per min; this curve is here reported using the first given temperature (1023 K) as reference temperature at which $\Delta L/L_0 = 0$.
29*	413	Richardson, J.H. and Zehms, E.H.	1963	T	3095-1372		The above specimen; expansion measured with decreasing temperature; this curve is here reported using the first given temperature (3095 K) as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction of -2.59%.

*Not shown in figure.

SPECIFICATION TABLE 19. THERMAL LINEAR EXPANSION OF PYROLYTIC GRAPHITE (continued)

Curv. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
30*	413	Richardson, J.H. and Zehms, E.H.	1963	T	1406-3242		Specimen prepared from a 0.125 in. thick central zone of 0.75 in. thick block (fabricated by the *High Temperature Materials Co., Boston, Mass.*) which formed at 2423 K with deposition time of 200 hrs; expansion measured along the c-axis perpendicular to basal plane with average heating rate 10 C per min; this curve is here reported using the first given temperature (1406 K) as reference temperature at which $\Delta L/L_0 = 0$.
31*	414	Pappis, J. and Blum, S. L.	1961		273-1343		Highly regenerative microstructure; deposited in graphite resistance furnace at 2373 K; density 2.2 g cm^{-3}; expansion measured along a-direction parallel to basal plane.
32	414	Pappis, J. and Blum, S. L.	1961		273-1347		Similar to the above specimen except heat-treated at 2973 K for 3 hrs.
33	414	Pappis, J. and Blum, S. L.	1961		273-1345		Singularly nucleated microstructure; deposited in a graphite resistance furnace at 2373 K; density = 2.2 g cm^{-3}; expansion measured along c-direction perpendicular to basal plane.
34	414	Pappis, J. and Blum, S. L.	1961		273-1343		Similar to the above specimen except heat-treated at 3273 K for 1 hr.
35*	414	Pappis, J. and Blum, S. L.	1961		273-1353		Singularly nucleated microstructure; deposited in a graphite resistance furnace at 2373 K; density = 2.2 g cm^{-3}; expansion measured along a-direction parallel to basal plane.
36*	414	Pappis, J. and Blum, S. L.	1961		273-1273		Similar to the above specimen except heat-treated at 2973 K for 3 hrs.
37*	415	Raytheon Company	1962		283-1348		Measured along a-direction parallel to the basal plane.
38	377	Lowell, C.E.	1963	X	298-2735		Specimen deposited at 2400 K and rebaked at 3400 K; sample self-heated by passing current through it; expansion measured in c-direction; lattice constant reported at 298 K is 6.7098 Å; 6.7090 Å at 293 K determined by graphical interpolation; coefficient of linear expansion also reported.
39	416	Gebhardt, J.J. and Berry, J.M.	1964		293-2989		Specimen obtained from Metallurgical Products Dept., General Electric Co.; surface nucleated; deposited at 2478 K; specimen cut from flat plate raw stock and all surfaces finished by grinding; density by immersion in alcohol 2.20 g cm^{-3}; expansion measured in a-direction.
40	416	Gebhardt, J.J. and Berry, J.M.	1964		293-2756		The above specimen except expansion measured in c-direction.
41	416	Gebhardt, J.J. and Berry, J.M.	1964		293-3050		Specimen obtained from Raytheon Manufacturing Co.; continuously nucleated; deposited at 2478 K; specimen cut from flat plate raw stock and all surfaces finished by grinding; density by immersion in alcohol 2.206 g cm^{-3}; expansion measured in a-direction.
42	416	Gebhardt, J.J. and Berry, J.M.	1964		293-2756		The above specimen except expansion measured in c-direction.
43	417	Entwisle, F.	1962	L	323-973		Specimen produced by deposition of graphite from the gaseous phase on to carbon substrate at 2473 K; supplied by High Temperature Materials, U.S.A.; heated in argon atmosphere at 3073 K for 8 hrs; 0.2 in. diameter and 1 in. long; expansion measured in a-direction; coefficient of linear expansion also reported.
44	417	Entwisle, F.	1962	L	323-973		Similar to the above specimen except 0.2 in. diameter and 0.2 in. long; expansion measured in c-direction; coefficient of linear expansion also reported.
45	418	Kellett, F.A. and Richards, B.P.	1964	X	77-328		Highly orientated pyrolytic graphite (p = 0.1), graphitized at 3253 K; 2 x 1.5 x 10 mm rod form; Philips PW1050 diffractometer used; lattice constant 2.4611 Å at 293.2 K determined by graphical interpolation.

*Not shown in figure.

SPECIFICATION TABLE 19. THERMAL LINEAR EXPANSION OF PYROLYTIC GRAPHITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
46	418	Kellett, E.A. and Richards, B.P.	1964	X	291-1523		Flakes of pyrolytic graphite (p = 0.1) cut into thin rods and mounted in alumina paste; unfiltered copper radiation used; lattice constant 2.4611 Å at 293.2 K determined by graphical interpolation.
47	418	Kellett, E.A. and Richards, B.P.	1964	X	1848-3327		Spectroscopic carbon rod p = 0.2, with little preferred orientation; 1 x 0.5 x 26 mm sample; observations confined to (11$\bar{2}$0) reflexions; specimen enclosure filled with argon at constant pressure; lattice constant of 2.4611 Å at 293.2 K used for data conversion.
48	418	Kellett, E.A. and Richards, B.P.	1964	X	1165-2135		Pyrolytic, p = 0.1 with high degree of preferred orinetation, had been graphitized at 3253 K; 1 x 0.5 x 26 mm sample; lattice constant of 2.4611 Å at 293.2 K used for data conversion.
49	367	Elliott, E.S. and Richardson, J.H.	1966	X	273-2673		Specimen prepared from 1.91 cm block of continuously nucleated material from national Carbon Co., High Temperature Materials Div.; deposited at 2423 K; lattice dimension expansion measured along c-axis; lattice dimension reported at 273 K is 6.835 Å; 6.837 Å at 293 K determined by graphical interpolation.
50	367	Elliott, E.S. and Richardson, J.H.	1966	X	273-3273		The above specimen; heat-treated 1 hr in argon at 3683 K; lattice dimension expansion measured on first test along c-axis; lattice dimension reported at 273 K is 6.745 Å; 6.747 Å at 293 K determined by graphical interpolation.
51	367	Elliott, E.S. and Richardson, J.H.	1966	X	273-3273		The above specimen; expansion measured on second test.
52	171	Asay, J.R., Urzondowski, S.R. and Guenther, A.H.	1968	L	173-473		Polycrystalline, vapor-deposited specimen; density 2.19 g cm^{-3}; expansion measured parallel to axis.
53*	583	Pojur, A.F., Yates, B., and Kelly, B.T.	1972	I	320-780		Specimen hemispherical shells with thickness of few hundreths of 1 mm and diameters of the order of 1 mm, high uncertainty arose from combined effect of small specimen size and low thermal expansion which together produced length changes of the order of 2 x 10^{-5} mm when temperature raised by typically 10 C.

* Not shown in figure.

DATA TABLE 19. THERMAL LINEAR EXPANSION OF PYROLYTIC GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
273	-0.002
1273	0.098
CURVE 2	
373	-0.0056
473	-0.0052
573	0.0004
673	0.0076
773	0.0217
873	0.0341
973	0.0487
1073	0.0643
1173	0.0821
1273	0.1007*
1348	0.1122
CURVE 3*	
373	-0.0028
473	0.0014
573	0.0098
673	0.0211
773	0.0359
873	0.0534
973	0.0716
1073	0.0911
1173	0.1105
1273	0.1234
1351	0.1407
CURVE 4*	
373	-0.0005
573	0.0206
673	0.0336
773	0.0460
873	0.0657
973	0.0836
1073	0.1046
1173	0.1266
1298	0.1478
1354	0.1635

T	$\Delta L/L_0$
CURVE 5	
373	0.19
473	0.42
573	0.69
673	0.93
773	1.16
873	1.41
973	1.67
1073	1.91
1173	2.16
1273	2.41
1347	2.56
CURVE 6	
373	0.17
473	0.33
573	0.67
673	0.89
773	1.11
873	1.32
973	1.55
1073	1.77
1173	1.97
1273	2.20
1351	2.35
CURVE 7	
373	0.23*
501	0.53
573	0.71*
673	0.93*
773	1.19*
902	1.49
973	1.70*
1073	1.93*
1173	2.18*
1273	2.36
1347	2.50
CURVE 8*	
373	-0.006
473	-0.006
573	0.002
673	0.009

T	$\Delta L/L_0$
CURVE 8 (cont.)*	
773	0.020
873	0.036
973	0.054
1073	0.073
1173	0.098
1273	0.114
1349	0.128
CURVE 9	
573	0.017*
773	0.048*
873	0.070*
973	0.092*
1073	0.115
1173	0.136
1349	0.177
CURVE 10	
373	-0.002*
473	0.004*
573	0.016*
673	0.032*
773	0.056*
873	0.083*
973	0.111
1073	0.142*
1173	0.172*
1273	0.202
1349	0.223*
CURVE 11	
373	0.13*
473	0.33*
573	0.61*
673	0.87*
773	1.09*
873	1.34*
973	1.53*
1073	1.73
1173	1.98*
1273	2.19*
1344	2.22

T	$\Delta L/L_0$
CURVE 12	
373	0.15*
473	0.39*
573	0.55
673	0.82
773	0.98
873	1.22
973	1.48
1073	1.79*
1173	1.92*
1273	2.13
1346	2.34*
CURVE 13	
373	0.26
473	0.64
573	0.99
673	1.28
773	1.59
873	1.86
973	2.15
1073	2.40
1173	2.65
1273	2.90
1346	3.05
CURVE 14	
373	0.19*
473	0.46*
573	0.73*
673	0.97*
773	1.20*
873	1.43*
973	1.68*
1073	1.87
1173	2.14*
1273	2.25
1345	2.37*
CURVE 15*	
373	-0.005
473	-0.002
573	0.005
673	0.015

T	$\Delta L/L_0$
CURVE 15 (cont.)*	
773	0.031
873	0.047
973	0.064
1073	0.080
1173	0.100
1273	0.178
1348	0.136
CURVE 16*	
373	0.008
473	0.009
573	0.025
673	0.046
773	0.068
873	0.089
973	0.118
1073	0.149
1173	0.182
1273	0.213
1353	0.235
CURVE 17*	
373	-0.009
473	-0.006
573	0.000
673	0.009
773	0.023
873	0.036
973	0.050
1073	0.065
1173	0.083
1273	0.102
1347	0.111
CURVE 18*	
373	0.14
473	0.40
573	0.62
673	0.86
773	1.09
873	1.36
973	1.56
1073	1.77

T	$\Delta L/L_0$
CURVE 18 (cont.)*	
1173	1.98
1273	2.20
1348	2.39
CURVE 19*	
373	0.15
473	0.44
573	0.71
673	0.95
773	1.19
873	1.43
973	1.69
1073	1.93
1173	2.18
1273	2.43
1348	2.59
CURVE 20	
293	0.0000
359	0.0012
509	0.0151
683	0.0413*
869	0.0921
1061	0.1674
CURVE 21	
293	0.0000*
315	0.0583
373	0.2152*
423	0.3770
497	0.5522*
531	0.6926
577	0.7631
621	0.8544
663	0.9509*
717	1.1363
765	1.2239
815	1.3937
869	1.3766*
923	1.7546
971	1.6224*
1017	1.8100
1069	1.9516*
1123	2.3365

*Not shown in figure.

DATA TABLE 19. THERMAL LINEAR EXPANSION OF PYROLYTIC GRAPHITE (continued)

T	$\Delta L/L_0$
CURVE 22	
293	0.0000*
363	0.0010*
513	0.0075*
687	0.0331
877	0.0712*
1081	0.1324
CURVE 23	
293	0.0000*
439	0.4198
485	0.5178
529	0.5251
603	0.8959
659	1.1126
699	1.1632
741	1.3664
787	1.3881
839	1.6680
885	1.6842
941	1.8468
999	1.9154
1049	2.2204
1099	2.2689
CURVE 24	
293	0.0000*
347	-0.0041
489	-0.0090
657	0.0000
833	0.0270
1025	0.0761
CURVE 25	
293	0.0000*
329	0.1044
461	0.4998
507	0.6292
593	0.8760
643	1.0255
693	1.1560*
745	1.3153
789	1.5178
837	1.5395
889	1.7922

T	$\Delta L/L_0$
CURVE 25 (cont.)	
941	1.8455*
995	1.9817
1057	2.1812
1125	2.4169
CURVE 26	
273	0.0000*
366	-0.0002*
477	0.0002*
588	0.001
699	0.003*
810	0.005
922	0.007
1033	0.009
1144	0.012
1188	0.013
CURVE 27	
273	0.0002*
366	-0.0006*
477	-0.0007*
588	0.0000*
699	0.0012*
810	0.0026*
922	0.0043*
1033	0.0062*
1144	0.0082*
1244	0.0102
CURVE 28*, †	
1023	0.00
1386	0.14
1523	0.20
1666	0.23
1823	0.28
1993	0.34
2010	0.36
2193	0.39
2316	0.48
2514	0.55
2754	0.69
2986	1.00
3142	1.91
3179	2.11

T	$\Delta L/L_0$
CURVE 28 (cont.)*, †	
3182	2.26
3183	2.32
3183	2.36
3186	2.41
3206	2.50
3206	2.55
CURVE 29*, †	
3095	0.00
2952	-0.09
2880	-0.10
2742	-0.14
2635	-0.17
2478	-0.23
2365	-0.26
2049	-0.35
1572	-0.47
1372	-0.53
CURVE 30*, †	
1406	0.00
1718	0.19
1922	0.51
2155	1.01
2571	1.75
2806	2.94
2966	3.90
3126	-0.24
3238	-4.11
3242	-5.38
CURVE 31*	
273	0.0013
373	-0.004
473	-0.002
573	0.003
673	0.013
773	0.029
873	0.044
973	0.060
1073	0.080
1173	0.101
1273	0.124
1343	0.141

T	$\Delta L/L_0$
CURVE 32	
273	0.001*
373	-0.014*
473	-0.021*
573	-0.026*
672	-0.019*
773	-0.013*
873	-0.005*
973	0.005*
1073	0.018*
1174	0.031
1273	0.045*
1347	0.056
CURVE 33	
273	-0.015*
369	0.200*
470	0.408*
573	0.681*
664	0.925*
775	1.185*
873	1.423*
973	1.665*
1073	1.982*
1173	2.105
1273	2.302*
1345	2.422
CURVE 34	
273	-0.050
377	0.210*
476	0.488*
573	0.733*
672	0.980*
777	1.270
873	1.503
973	1.800
1074	2.030
1173	2.285
1273	2.535
1343	2.730
CURVE 35*	
273	0.002
373	-0.010

T	$\Delta L/L_0$
CURVE 35 (cont.)*	
474	-0.008
573	-0.002
673	0.009
773	0.022
873	0.036
973	0.052
1073	0.070
1173	0.088
1274	0.107
1353	0.120
CURVE 36*	
273	0.001
373	-0.013
463	-0.016
581	-0.016
671	-0.008
773	0.008
873	0.020
964	0.032
1073	0.052
1173	0.067
1273	0.084
CURVE 37*	
283	0.001
374	-0.005
574	0.014
675	0.032
773	0.045
873	0.062
976	0.083
1073	0.103
1173	0.126
1280	0.147
1348	0.163
CURVE 38	
6	-0.5187
78	-0.4859
193	-0.2325
298	0.0119*
1036	2.1612
1095	2.1910

T	$\Delta L/L_0$
CURVE 38 (cont.)	
1127	2.0420
1192	2.5786
1238	2.3401
1311	2.9959
1343	2.7574*
1391	2.9363
1462	3.0555
1483	3.2642
1529	3.3537
1647	3.8306
1683	4.1884
1758	4.1287
1802	4.3970
1810	4.4865
1899	4.8144
1954	4.9038
1987	4.9932
2060	5.2913
2085	5.3510
2150	5.6193
2195	5.8279
2309	6.2751
2360	6.4838
2400	6.6925
2448	6.5434
2494	7.1396
2569	7.2589
2633	7.7358
2731	8.2426
CURVE 39	
293	0.000*
394	-0.005
533	-0.002
810	0.020*
1088	0.070
1366	0.122
1644	0.195
1922	0.285
2199	0.385
2477	0.485
2755	0.600
2894	0.660
2988	0.850

*Not shown in figure.

†This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 19. THERMAL LINEAR EXPANSION OF PYROLYTIC GRAPHITE (continued)

T	$\Delta L/L_0$
CURVE 40	
293	0.00*
533	0.60
810	1.36*
1088	2.12*
1366	2.88
1644	3.64
1922	4.40
2199	5.16
2477	5.90
2755	6.68
CURVE 41	
293	0.000*
394	0.000*
533	0.005*
810	0.040*
1088	0.100*
1366	0.170*
1644	0.255
1922	0.345
2199	0.445
2477	0.545
2755	0.670
2894	0.765
3033	1.000
3050	1.210
CURVE 42	
293	0.00*
533	0.48
810	1.24
1088	1.96
1366	2.72
1644	3.46
1922	4.18
2199	4.90
2477	5.64
2755	6.40
CURVE 43	
323	-0.0030
373	-0.0050*
423	-0.0102
473	-0.0149*
523	-0.0198*
CURVE 43 (cont.)	
573	-0.0235*
623	-0.0239
673	-0.0242*
723	-0.0230
773	-0.0215*
823	-0.0180*
873	-0.0141*
923	-0.0104*
973	-0.0061*
CURVE 44	
323	0.060*
373	0.175*
423	0.300
473	0.430*
523	0.570*
573	0.710*
623	0.865*
673	1.010
723	1.155
773	1.300*
823	1.450
873	1.600
923	1.740*
973	1.890
CURVE 45	
77	0.0243
103	0.0203
123	0.0162
133	0.0162
153	0.0243
158	0.0121
163	0.0121
173	0.0081
193	0.0162
213	0.0121
241	0.0081
313	-0.0040*
328	-0.0081*
CURVE 46	
291	0.0040*
423	-0.0243*
473	-0.0243*
CURVE 46 (cont.)	
623	-0.0162*
823	-0.0243*
923	-0.0040*
1073	0.0040*
1173	0.0243*
1373	0.0284
1523	0.0365
CURVE 47	
1848	0.0853
1898	0.0893
2216	0.1178
2389	0.1300
2583	0.1665
2648	0.1584
2795	0.1950
3056	0.2194
3327	0.2762
CURVE 48	
1165	0.0203*
1488	0.0446
1585	0.0568
1682	0.0853
1743	0.0609
1831	0.0731
2016	0.1056
2135	0.1137
CURVE 49	
273	-0.029*
1073	2.004*
1173	2.282*
1273	2.574*
1373	2.838*
1473	3.072*
1573	3.364
1673	3.686
1773	3.890
1873	4.110
1973	4.329
2073	4.651
2173	5.017
2273	5.338
2373	5.514
CURVE 49 (cont.)	
2473	5.807
2573	6.011
2673	6.377
CURVE 50	
273	-0.030*
1172	2.416
1273	2.742
1371	2.890*
1472	3.098*
1572	3.557
1672	3.898
1772	4.091
1872	4.298
1973	4.669
2073	4.980
2173	5.217
2272	5.588
2373	5.766
2472	6.092
2571	6.358
2673	6.744
2773	7.025
2873	7.322
2973	7.588
3076	7.826
3173	8.137
3273	8.315
CURVE 51	
273	-0.030*
293	0.000*
1172	2.194*
1273	2.342*
1371	2.890*
1472	3.216
1572	3.438
1672	3.794
1772	4.091*
1872	4.402
1973	4.669*
2073	4.891
2173	5.217*
2272	5.469
2373	5.854
2472	6.017*
CURVE 51 (cont.)	
2571	6.492
2673	6.640
2773	6.936
2873	7.234
2973	7.500*
3076	7.929
3173	8.078
3273	8.418
CURVE 52‡	
173	-0.225
183	-0.212
193	-0.197
203	-0.181
213	-0.163
223	-0.144
233	-0.125
243	-0.106
253	-0.087
263	-0.066
273	-0.044*
283	-0.022*
293	0.000*
303	0.022*
313	0.046*
323	0.070*
333	0.095*
343	0.120
353	0.145
363	0.170*
373	0.195*
383	0.221
393	0.246
403	0.272
413	0.298
423	0.324*
433	0.351*
443	0.378
453	0.406
463	0.435*
473	0.465*
CURVE 53*,‡	
320	0.013
340	0.022
360	0.031
CURVE 53 (cont.) *,‡	
380	0.041
400	0.051
420	0.061
440	0.071
460	0.081
480	0.092
500	0.102
520	0.113
540	0.124
560	0.134
580	0.145
600	0.156
620	0.167
640	0.178
660	0.190
680	0.201
700	0.212
720	0.223
740	0.234
760	0.246
780	0.257

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 19. COEFFICIENT OF THERMAL LINEAR EXPANSION OF PYROLYTIC GRAPHITE

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

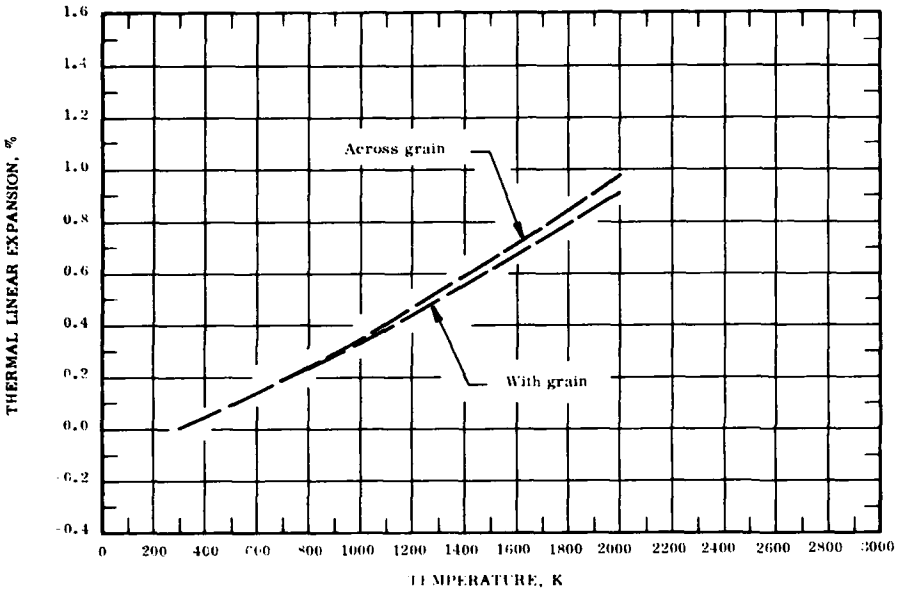
T	α
CURVE 38*	
800	25.4
900	25.6
1000	26.5
1100	27.1
1200	28.1
1300	28.7
1400	30.0
1500	30.7
1600	32.2
1700	32.1
1800	33.9
1900	35.1
2000	36.3
2100	36.8
2200	38.3
2300	38.5
2400	40.7
2500	41.9
CURVE 43*	
323	-0.869
373	-0.914
423	-0.926
473	-0.920
523	-0.738
573	-0.423
623	-0.147
673	0.085
723	0.306
773	0.497
823	0.700
873	0.814
923	0.818
CURVE 44*	
323	23.69
373	24.72
423	26.20
473	26.82
523	27.63
573	28.41
623	29.11
673	29.43
723	29.36

T	α
CURVE 44 (cont.)*	
773	28.91
823	29.14
873	29.16
923	28.54
CURVE 52‡	
173	13.0
183	13.8
193	15.5
203	17.2
213	18.2
223	19.0
233	19.0
243	18.9
253	20.5
263	21.6
273	21.6
283	22.2
293	22.3
303	22.6*
313	24.3*
323	24.4*
333	24.9*
343	25.0*
353	25.1*
363	25.2*
373	25.2*
383	25.6*
393	25.6*
403	25.9*
413	25.9*
423	26.6*
433	26.9*
443	27.3*
453	29.0*
463	29.4*
473	29.6*
CURVE 53*,‡	
320	4.62
340	4.71
360	4.80
380	4.88
400	4.96

T	α
CURVE 53 (cont.)*,‡	
420	5.03
440	5.10
460	5.17
480	5.23
500	5.28
520	5.34
540	5.38
560	5.43
580	5.47
600	5.50
620	5.53
640	5.56
660	5.58
680	5.59
700	5.61
720	5.61
740	5.62
760	5.62
780	5.61

*Not shown in figure.
‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 20R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE RT0029 GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	3.9	0.000	3.9
400	0.044	4.3	0.044	4.3
600	0.136	4.9	0.134	4.7
800	0.239	5.4	0.231	5.0
1000	0.351	5.8	0.335	5.3
1200	0.470	6.1	0.444	5.6
1400	0.594	6.3	0.557	5.8
1600	0.721	6.4	0.674	5.9
1800	0.851	6.5	0.794	6.0
2000	0.979	6.5	0.915	6.1

REMARKS

The provisional values are considered accurate to within ±7% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.099 + 2.822 \times 10^{-4} T + 2.073 \times 10^{-7} T^2 - 3.937 \times 10^{-11} T^3$

With grain: $\Delta L/L_0 = -0.108 + 3.316 \times 10^{-4} T + 1.321 \times 10^{-7} T^2 - 2.109 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

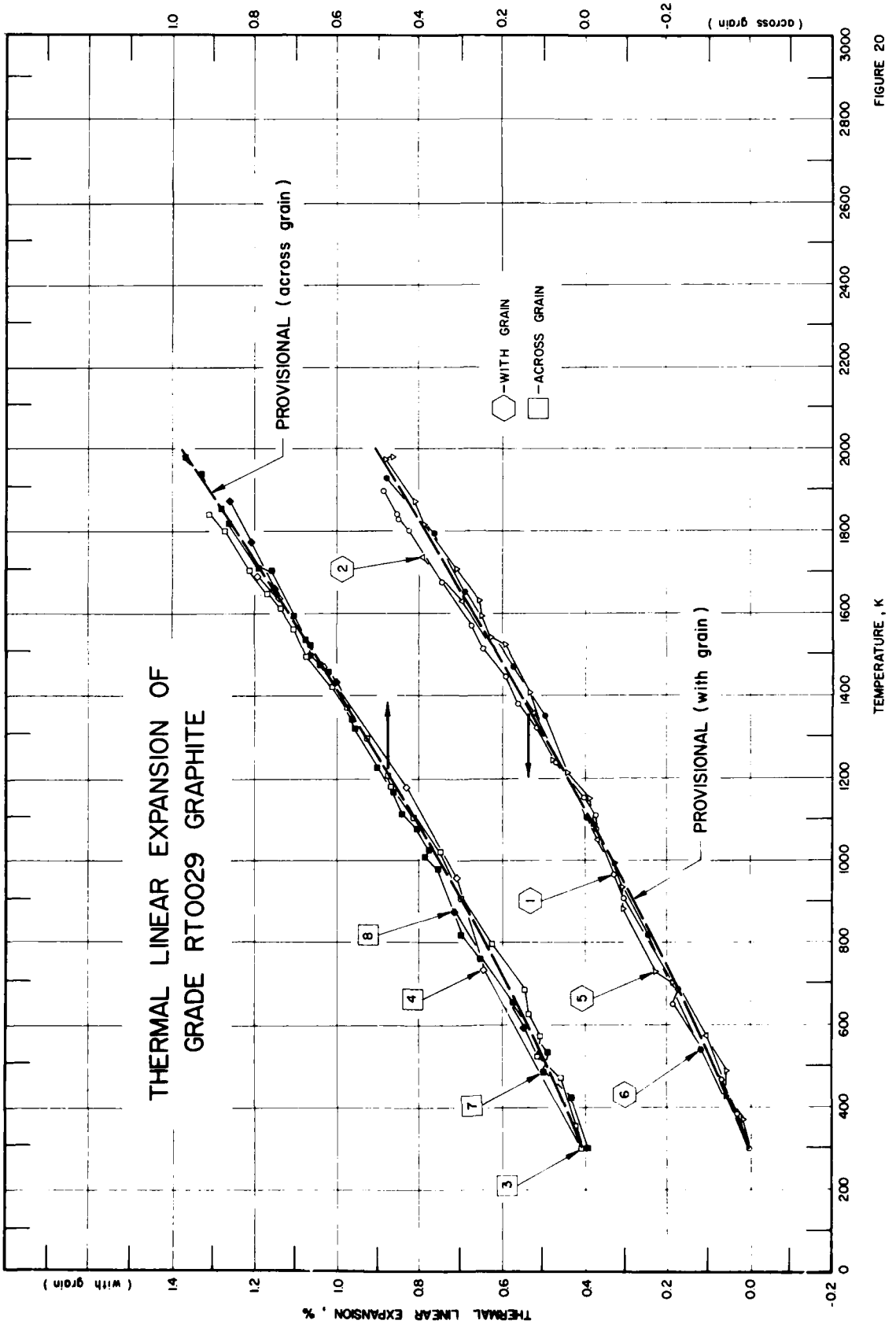

THERMAL LINEAR EXPANSION OF
GRADE RT0029 GRAPHITE
PROVISIONAL (across grain)
PROVISIONAL (with grain)
WITH GRAIN
ACROSS GRAIN
THERMAL LINEAR EXPANSION , %
(with grain)
(across grain)
TEMPERATURE , K
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1
2
3
4
5
6
7
8

FIGURE 20

SPECIFICATION TABLE 20. THERMAL LINEAR EXPANSION OF GRADE RT0029 GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	390	Rogers, D. C.	1963		293-1891		Bare specimen obtained from National Carbon Co.; expansion measured parallel to grain direction.
2	390	Rogers, D. C.	1963		1736-293		The above specimen; expansion measured with decreasing temperature.
3	390	Rogers, D. C.	1963		293-1836		The above specimen; expansion measured perpendicular to grain direction; zero-point correction of -0. 011%.
4	390	Rogers, D. C.	1963		1685-293		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0. 011%.
5	390	Rogers, D. C.	1963		293-1973		Siliconized specimen; expansion measured parallel to grain direction; zero-point correction of -0. 008%.
6	390	Rogers, D. C.	1963		1922-293		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0. 008%.
7	390	Rogers, D. C.	1963		293-1975		Similar to the above specimen; expansion measured perpendicular to grain direction; zero-point correction of 0. 012%.
8	390	Rogers, D. C.	1963		1867-293		The above specimen; expansion measured with decreasing temperature; zero-point correction of 0. 012%.

DATA TABLE 20. THERMAL LINEAR EXPANSION OF GRADE RT0029 GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
293	0.000
380	0.031
468	0.068
650	0.184
685	0.170
905	0.301
960	0.327
1077	0.368
1107	0.368
1150	0.407
1234	0.470
1319	0.516
1377	0.560
1441	0.591
1513	0.644
1566	0.675
1672	0.743
1793	0.827
1825	0.854
1838	0.859
1891	0.890

CURVE 2

T	$\Delta L/L_0$
1736	0.791
1628	0.699
1355	0.523
1044	0.362
571	0.102
293	0.000

CURVE 3

T	$\Delta L/L_0$
293	0.000
296	0.005
357	0.020
470	0.054
524	0.110
572	0.107
627	0.132
683	0.140
794	0.212
905	0.295
1020	0.342
1105	0.415
1179	0.467

CURVE 3 (cont.)

T	$\Delta L/L_0$
1204	0.477
1292	0.524
1366	0.577
1419	0.611
1496	0.678
1559	0.704
1606	0.736
1644	0.763
1703	0.814
1791	0.874
1836	0.917

CURVE 4

T	$\Delta L/L_0$
1685	0.794
1634	0.740
1467	0.634
1177	0.434
953	0.309
736	0.240
293	0.000

CURVE 5

T	$\Delta L/L_0$
293	0.000
365	0.010
424	0.055
484	0.055
700	0.182
729	0.230
876	0.304
930	0.308
987	0.323
1085	0.378
1147	0.383
1208	0.441
1240	0.479
1401	0.529
1525	0.592
1540	0.626
1588	0.649
1630	0.656
1705	0.709
1816	0.785
1867	0.812
1968	0.884
1973	0.870

CURVE 6

T	$\Delta L/L_0$
1922	0.844
1790	0.760
1647	0.690
1471	0.572
1348	0.495
1101	0.397
815	0.243
538	0.114
293	0.000

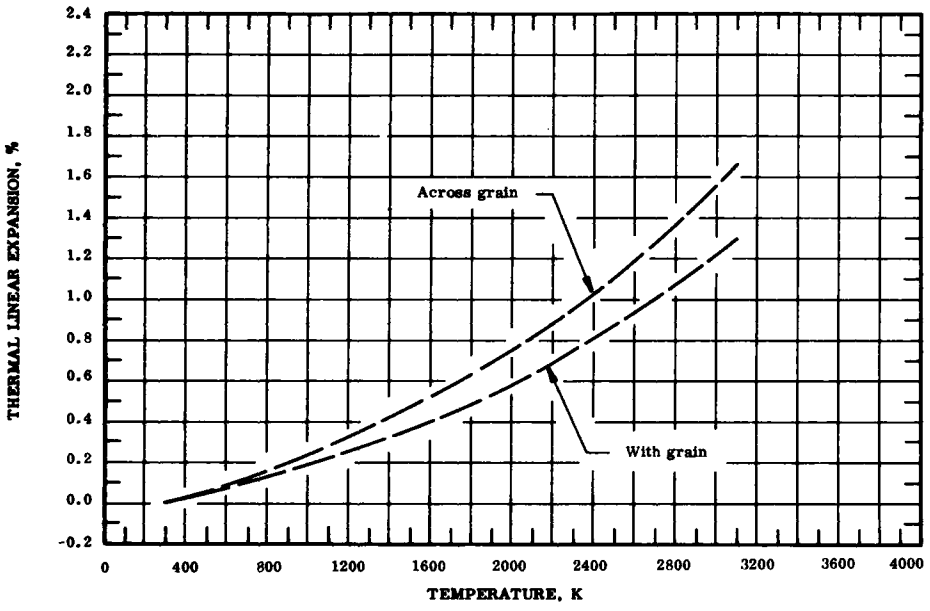
CURVE 7

T	$\Delta L/L_0$
293	0.000
300	-0.011
425	0.026
483	0.094
539	0.088
655	0.169
760	0.248
817	0.293
975	0.352
1006	0.381
1022	0.374
1076	0.406
1114	0.441
1165	0.465
1180	0.467
1223	0.502
1319	0.557
1340	0.561
1365	0.574
1457	0.620
1471	0.640
1498	0.669
1521	0.668
1537	0.678
1591	0.705
1602	0.733
1701	0.756
1707	0.787
1817	0.863
1854	0.882
1934	0.934
1975	0.968

CURVE 8

T	$\Delta L/L_0$
1867	0.864
1768	0.809
1660	0.750
1431	0.603
871	0.311
593	0.141
293	0.000

FIGURE AND TABLE NO. 21R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE RVA GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	2.8	0.000	2.3
400	0.031	3.0	0.025	2.4
600	0.093	3.3	0.075	2.6
800	0.162	3.6	0.129	2.8
1000	0.237	4.0	0.189	3.1
1200	0.320	4.4	0.254	3.4
1400	0.412	4.8	0.326	3.8
1600	0.513	5.3	0.405	4.1
1800	0.624	5.8	0.492	4.6
2000	0.747	6.4	0.588	5.0
2200	0.881	7.0	0.692	5.5
2400	1.029	7.7	0.807	6.0
2600	1.190	8.4	0.932	6.5
2800	1.366	9.2	1.068	7.1
3000	1.557	9.9	1.217	7.7
3100	1.658	10.4	1.295	8.0

REMARKS

The provisional values are considered accurate to within ± 10% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.078 + 2.524 \times 10^{-4} T + 4.517 \times 10^{-8} T + 1.745 \times 10^{-11} T^3$

With grain: $\Delta L/L_0 = -0.063 + 2.061 \times 10^{-4} T + 3.222 \times 10^{-8} T^2 + 1.377 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 10%

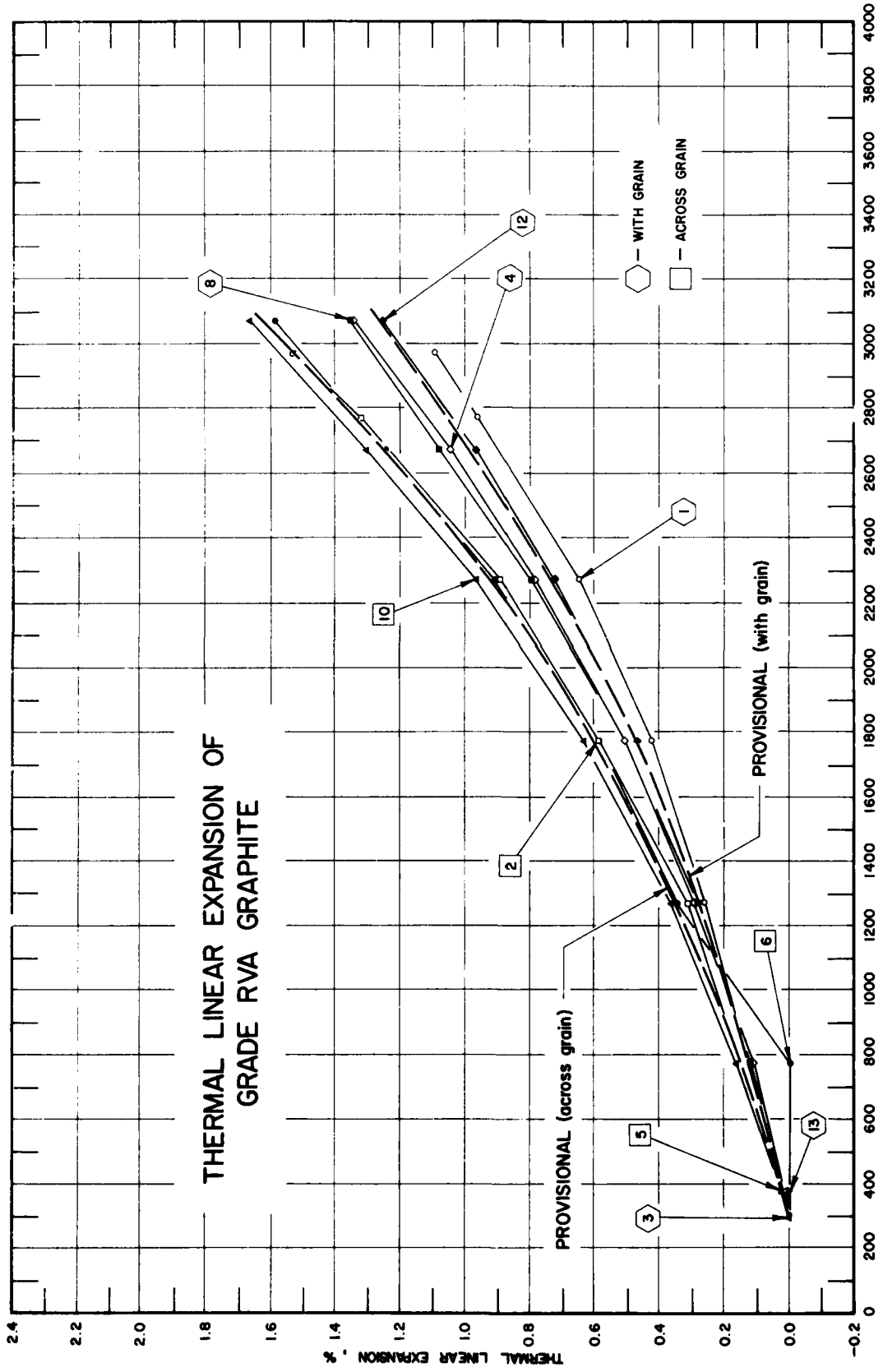

THERMAL LINEAR EXPANSION OF
GRADE RVA GRAPHITE
— WITH GRAIN
— ACROSS GRAIN
PROVISIONAL (with grain)
PROVISIONAL (across grain)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
1
2
3
4
5
6
8
10
12
13

FIGURE 21

SPECIFICATION TABLE 21. THERMAL LINEAR EXPANSION OF GRADE RVA GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	379	Lafyatis, P. G., Waters, C. W. and Dull, R. B.	1965	T	303-2978		Material formed in cylinder 58 in. O. D., 30 in. I. D., 40 in. long; eight specimen cut to 0. 50 x 0. 50 x 5 in. and tested; average results given for expansion measured with grain; reported error 5. 0%; zero-point correction of 0. 000% determined by graphical extrapolation.
2	379	Lafyatis, P. G., et al.	1965	T	303-2978		The above specimen except expansion measured across grain; zero-point correction of 0. 000% determined by graphical extrapolation.
3	371	Dull, R. B.	1964	O	293, 373	Block No. A-19	Specimen dimensions 0. 3 x 0. 375 x 5 in.; obtained from National Carbon Co.; 33 in. diameter, 42 in. long block; bulk density 1. 825 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 12. 25 x 10^{-4} ohm-cm, across grain 16. 87 x 10^{-4} ohm-cm; average data over several runs; expansion measured with grain.
4	371	Dull, R. B.	1964	T	293-3073	Block No. A-19	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured with grain.
5	371	Dull, R. B.	1964	O	293, 373	Block No. A-19	Specimen taken from same block as above specimen; specimen dimensions 0. 3 x 0. 375 x 5 in.; expansion measured across grain.
6	371	Dull, R. B.	1964	T	293-3073	Block No. A-19	Specimen taken from same block as above specimen; *specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured* across grain.
7*	371	Dull, R. B.	1964	O	293, 373	Block No. A-20	Specimen dimensions 0. 3 x 0. 375 x 5 in.; obtained from National Carbon Co.; 33 in. diameter, 42 in. block; bulk density 1. 842 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 12. 34 x 10^{-4} ohm-cm, across grain 15. 20 x 10^{-4} ohm-cm; average data over several runs; expansion measured with grain.
8	371	Dull, R. B.	1964	T	293-3073	Block No. A-20	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured with grain.
9*	371	Dull, R. B.	1964	O	293, 373	Block No. A-20	Specimen taken from same block as above specimen; specimen dimensions 0. 3 x 0. 375 x 5 in.; expansion measured across grain.
10	371	Dull, R. B.	1964	T	293-3073	Block No. A-20	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured across grain.
11*	371	Dull, R. B.	1964	O	293, 373	Block No. A-24	Specimen dimensions 0. 3 x 0. 375 x 5 in.; obtained from National Carbon Co.; 33 in. diameter, 42 in. long block; average data over several runs; bulk density 1. 841 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 12. 06 x 10^{-4} ohm-cm, across grain 15. 65 x 10^{-4} ohm-cm; expansion measured with grain.
12	371	Dull, R. B.	1964	T	293-3073	Block No. A-24	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured with grain.
13	375	Turner, J. H. and Carter, M. B.	1964		293, 373		Specimen 0. 50 x 0. 50 x 1 in.; expansion measured with grain.
14*	375	Turner, J. H. and Carter, M. B.	1964		293, 373		The above specimen; expansion measured across grain.

* Not shown in figure.

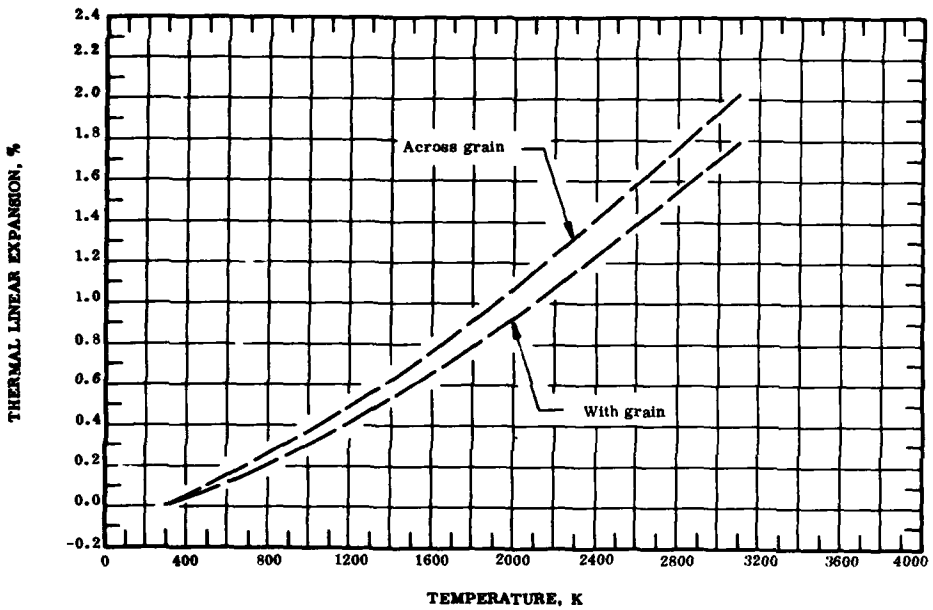
DATA TABLE 21. THERMAL LINEAR EXPANSION OF GRADE RVA GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
303	0.000
1273	0.265
1773	0.424
2273	0.646
2775	0.962
2978	1.091
CURVE 2	
303	0.000*
1273	0.316
1773	0.587
2273	0.899
2773	1.322
2978	1.531
CURVE 3	
293	0.000
373	0.013
CURVE 4	
293	0.000*
773	0.117
1273	0.297
1773	0.510
2273	0.783
2673	1.044
3073	1.345
CURVE 5	
293	0.000*
373	0.023
CURVE 6	
293	0.000*
773	0.000
1273	0.350
1773	0.588*
2273	0.915
2673	1.247
3073	1.583
CURVE 7*	
293	0.000
373	0.014
CURVE 8	
293	0.000*
773	0.121
1273	0.287
1773	0.516*
2273	0.793
2673	1.080
3073	1.350
CURVE 9*	
293	0.000
373	0.022
CURVE 10	
293	0.000*
773	0.161
1273	0.367
1773	0.636
2273	0.969
2673	1.308
3073	1.665
CURVE 11*	
293	0.000
373	0.012
CURVE 12	
293	0.000*
773	0.111*
1273	0.279*
1773	0.473
2273	0.728
2673	0.968
3073	1.258
CURVE 13	
293	0.00*
373	0.01
CURVE 14*	
293	0.00
373	0.02

* Not shown in figure.

FIGURE AND TABLE NO. 22R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE RVC GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	3.9	0.000	3.1
400	0.043	4.2	0.035	3.4
600	0.135	4.9	0.110	4.1
800	0.239	5.5	0.197	4.7
1000	0.354	6.1	0.296	5.2
1200	0.481	6.6	0.405	5.7
1400	0.617	7.0	0.523	6.1
1600	0.761	7.4	0.650	6.5
1800	0.914	7.8	0.784	6.9
2000	1.073	8.1	0.925	7.2
2200	1.237	8.4	1.072	7.5
2400	1.406	8.6	1.224	7.7
2600	1.579	8.7	1.380	7.9
2800	1.754	8.8	1.539	8.0
3000	1.931	8.9	1.701	8.1
3100	2.020	8.9	1.782	8.1

REMARKS

The provisional values are considered accurate to within ±10% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.097 + 2.759 \times 10^{-4}\ T + 1.968 \times 10^{-7}\ T^2 - 2.112 \times 10^{-11}\ T^3$

With grain: $\Delta L/L_0 = -0.075 + 2.041 \times 10^{-4}\ T + 1.857 \times 10^{-7}\ T^2 - 1.879 \times 10^{-11}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

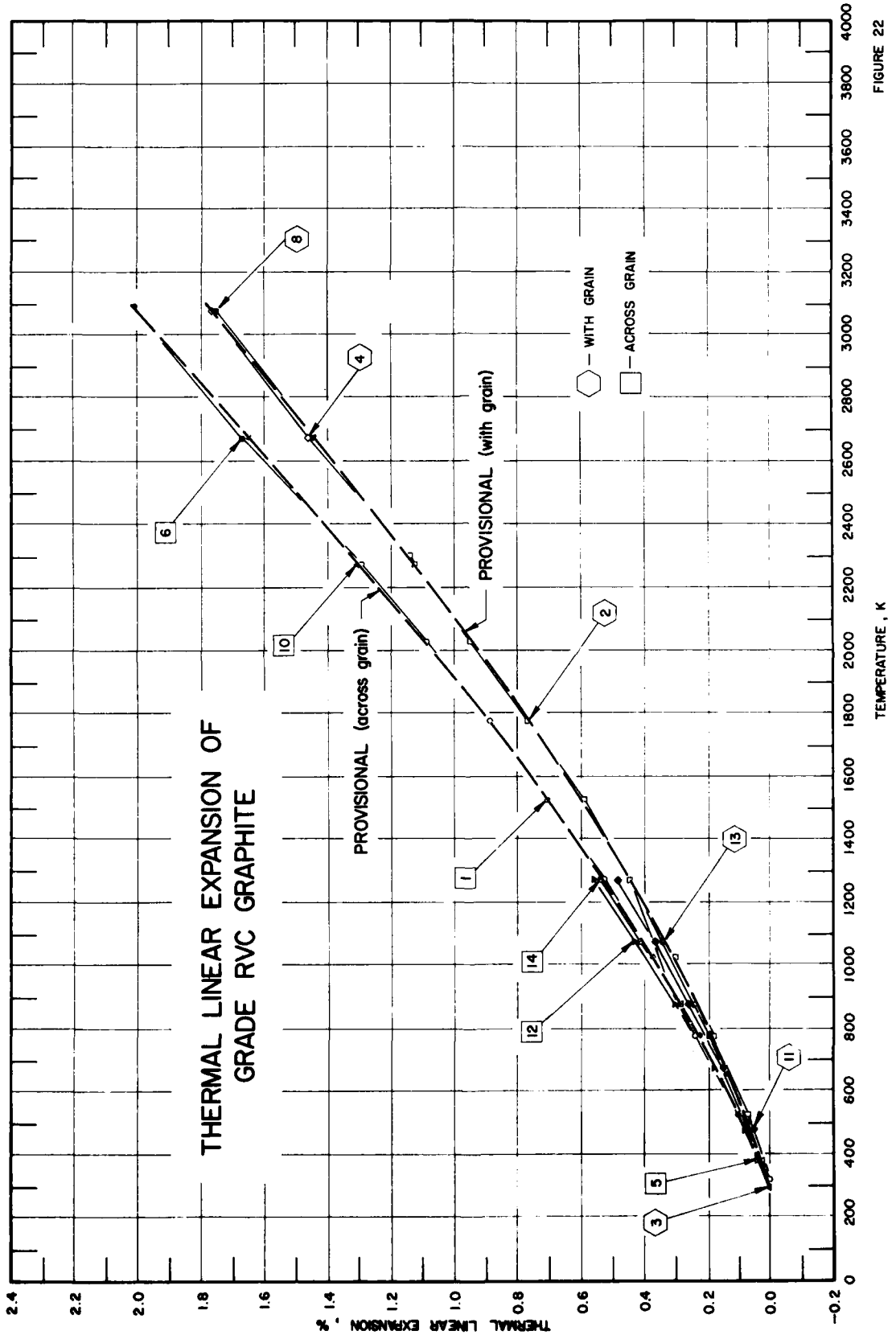

THERMAL LINEAR EXPANSION OF
GRADE RVC GRAPHITE
PROVISIONAL (with grain)
PROVISIONAL (across grain)
— WITH GRAIN
— ACROSS GRAIN
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
1
2
3
4
5
6
8
10
11
12
13
14

FIGURE 22

SPECIFICATION TABLE 22. THERMAL LINEAR EXPANSION OF GRADE RVC GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	387	James, D. R. and Hjelm, L. N.	1964		320-2273		Expansion measured across grain; zero-point correction of 0. 000% determined by graphical extrapolation.
2	387	James, D. R. and Hjelm, L. N.	1964		320-2304		Expansion measured with grain; zero-point correction of 0. 000% determined by graphical extrapolation.
3	371	Dull, R. B.	1964	O	293, 373	Block No. 163	Specimen dimensions 0. 3 x 0. 375 x 5 in.; obtained from National Carbon Co.; specimen taken from 18 in. diameter by 17 in. long block; bulk density 1. 84 g cm^{-3} at room temperature; specific resistance at room temperature with grain 12. 71 x 10^{-4} ohm-cm, across grain 16. 03 x 10^{-4} ohm-cm; average data over several runs; expansion measured with grain.
4	371	Dull, R. B.	1964	T	293-3073	Block No. 163	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured with grain.
5	371	Dull, R. B.	1964	O	293, 373	Block No. 163	Specimen taken from same block as above specimen; specimen dimensions 0. 3 x 0. 375 x 5 in.; expansion measured across grain.
6	371	Dull, R. B.	1964	T	293-3073	Block No. 163	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured across grain.
7*	371	Dull, R. B.	1964	O	293, 373	Block No. 175	Specimen dimensions 0. 3 x 0. 375 x 5 in.; obtained from National Carbon Co.; 18 in. diameter, 17 in. long block; bulk density 1. 85 g cm^{-3} at room temperature, specific resistance at room temperature with grain 13. 13 x 10^{-4} ohm-cm, across grain 16. 75 x 10^{-4} ohm-cm; average data over several runs.
8	371	Dull, R. B.	1964	T	293-3073	Block No. 175	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured with grain.
9*	371	Dull, R. B.	1964	O	293, 373	Block No. 175	Specimen taken from same block as above specimen; specimen dimensions 0. 3 x 0. 375 x 5 in.; expansion measured across grain.
10	371	Dull, R. B.	1964	T	293-3073	Block No. 175	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured across grain.
11	391	Howard, R. A. and Racicot, R. L.	1964		293-1273		Specimen obtained from National Carbon Co.; precompacted; expansion measured with grain.
12	391	Howard, R. A. and Racicot, R. L.	1964		293-1273		The above specimen; expansion measured across grain.
13	391	Howard, R. A. and Racicot, R. L.	1964		293-1273		Specimen obtained from National Carbon Co.; expansion measured with grain.
14	391	Howard, R. A. and Racicot, R. L.	1964		293-1273		The above specimen; expansion measured across grain.

* Not shown in figure.

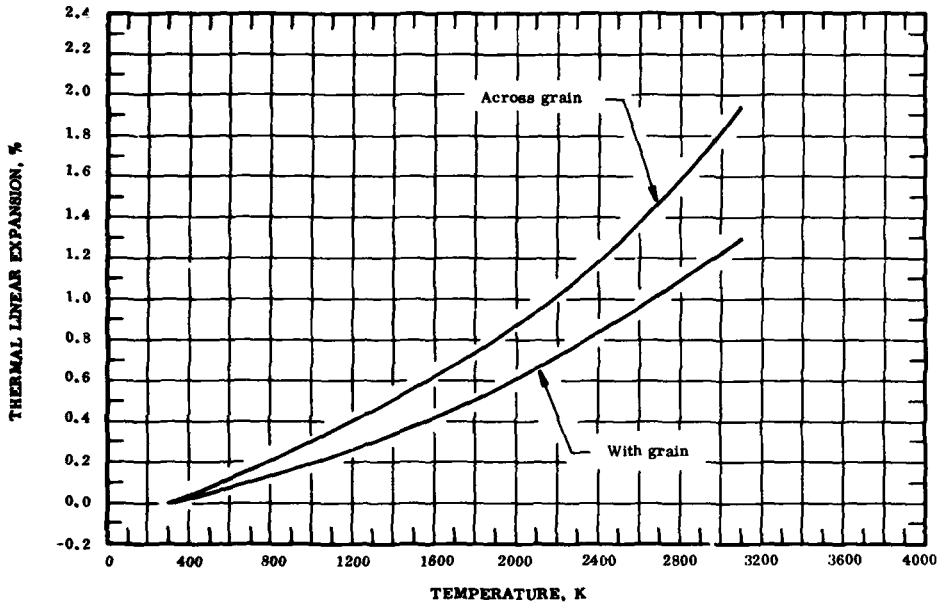
DATA TABLE 22. THERMAL LINEAR EXPANSION OF GRADE RVC GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
320	0.000
524	0.104
775	0.245
1024	0.375
1273	0.533
1524	0.710
1775	0.888
2023	1.095
2273	1.292
CURVE 2	
320	0.000*
523	0.078
774	0.184
1023	0.309
1274	0.448
1522	0.592
1774	0.769
2022	0.951
2274	1.132
2304	1.143
CURVE 3	
293	0.000
373	0.029
CURVE 4	
293	0.000*
773	0.195*
1273	0.447*
1773	0.769*
2273	1.127*
2673	1.460
3073	1.762
CURVE 5	
293	0.000*
373	0.035
CURVE 6	
293	0.000*
773	0.234
1273	0.528*
1773	0.883*
2273	1.290*
2673	1.672
3073	2.017
CURVE 7*	
293	0.000
373	0.030
CURVE 8	
293	0.000*
773	0.195
1273	0.452*
1773	0.770*
2273	1.136*
2673	1.446
3073	1.758
CURVE 9*	
293	0.000
373	0.036
CURVE 10	
293	0.000*
773	0.234*
1273	0.530*
1773	0.883*
2273	1.302
2673	1.653
3073	2.005*
CURVE 11	
293	0.000*
473	0.060
673	0.156
873	0.266
1073	0.370
1273	0.488
CURVE 12	
293	0.000*
473	0.088
673	0.184
873	0.310
1073	0.432
1273	0.562
CURVE 13	
293	0.000*
473	0.070
673	0.152*
873	0.244
1073	0.350
1273	0.456*
CURVE 14	
293	0.000*
473	0.082*
673	0.184*
873	0.294
1073	0.416
1273	0.540

* Not shown in figure.

FIGURE AND TABLE NO. 23R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF GRADE RVD GRAPHITE



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	4.0	0.000	1.9
400	0.043	4.0	0.022	2.1
600	0.123	4.1	0.068	2.5
800	0.207	4.3	0.122	2.9
1000	0.296	4.6	0.185	3.3
1200	0.391	5.0	0.254	3.7
1400	0.494	5.4	0.332	4.1
1600	0.608	5.9	0.418	4.5
1800	0.733	6.6	0.511	4.9
2000	0.871	7.3	0.612	5.2
2200	1.025	8.1	0.720	5.6
2400	1.196	9.0	0.837	6.0
2600	1.385	10.0	0.961	6.4
2800	1.594	11.0	1.093	6.8
3000	1.826	12.2	1.232	7.2
3100	1.950	12.8	1.305	7.4

REMARKS

The recommended values are considered accurate to within ±5% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.116 + 4.030 \times 10^{-4} T - 2.635 \times 10^{-6} T^2 + 3.596 \times 10^{-11} T^3$

With grain: $\Delta L/L_0 = -0.047 + 1.345 \times 10^{-4} T + 9.809 \times 10^{-6} T^2 - 2.422 \times 10^{-13} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±7%.

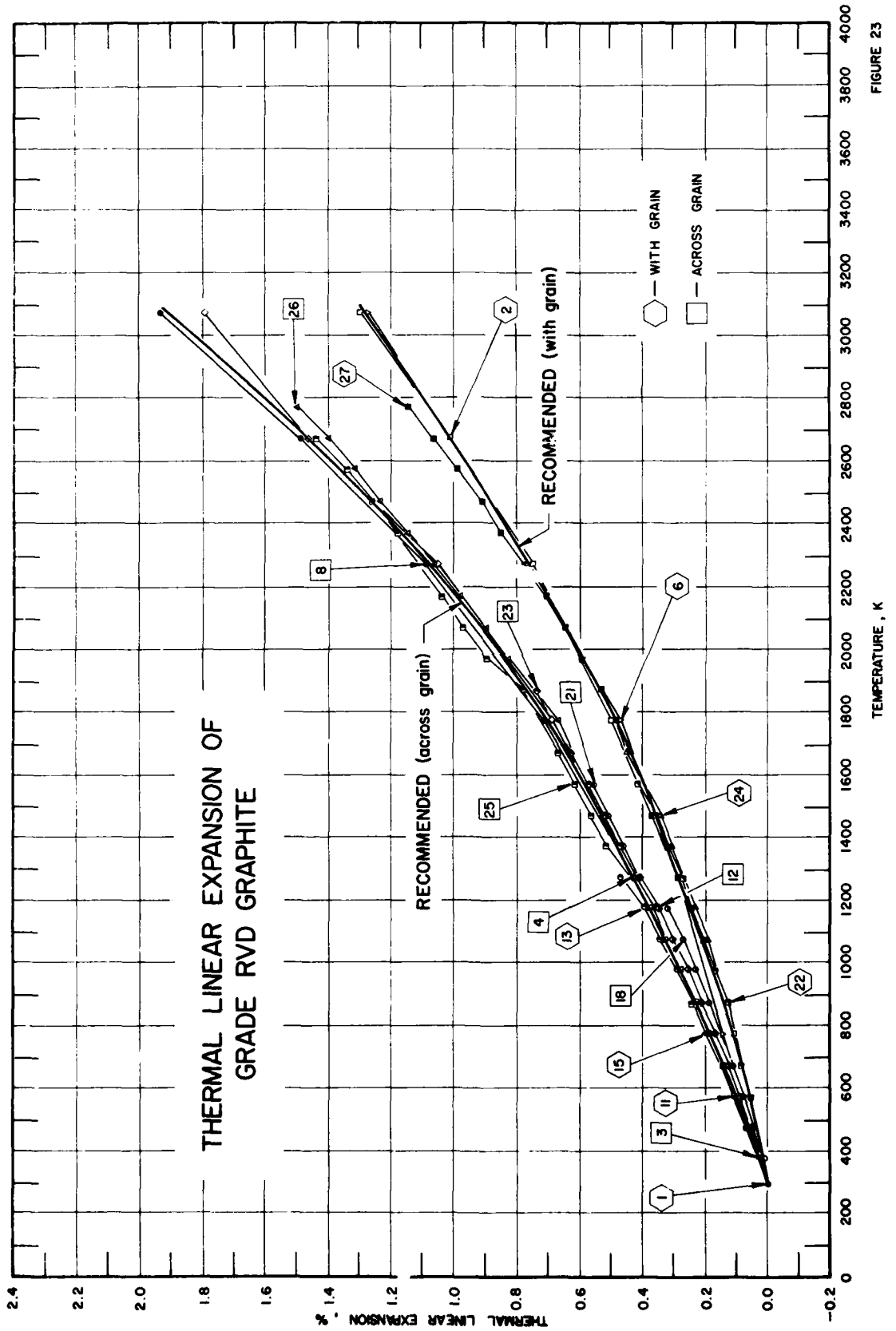

THERMAL LINEAR EXPANSION OF
GRADE RVD GRAPHITE
RECOMMENDED (with grain)
RECOMMENDED (across grain)
— WITH GRAIN
— ACROSS GRAIN
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
1
2
3
4
6
8
11
12
13
15
18
21
22
23
24
25
26
27

FIGURE 23

SPECIFICATION TABLE 23. THERMAL LINEAR EXPANSION OF GRADE RVD GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	371	Dull, R. B.	1964	O	293, 373	Block No. 199	Specimen dimensions 0. 3 x 0. 375 x 5 in.; obtained from National Carbon Co.; taken from 18 in. dia, 17 in. long block; bulk density 1.87 g cm^{-3} at room temperature; specific resistance at room temperature with grain 12. 52 x 10^{-4} ohm-cm, across grain 21. 72 x 10^{-4} ohm-cm; expansion measured with grain; average data over several runs.
2	371	Dull, R. B.	1964	T	293-3073	Block No. 199	*Specimen taken from same block as above specimen; specimen dimensions* 0. 50 x 0. 50 x 5 in.; expansion measured with grain.
3	371	Dull, R. B.	1964	O	293, 373	Block No. 199	Specimen taken from same block as above specimen; specimen dimensions 0. 3 x 0. 375 x 5 in.; expansion measured across grain.
4	371	Dull, R. B.	1964	T	293-3073	Block No. 199	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured across grain.
5*	371	Dull, R. B.	1964	O	293, 373	Block No. 200	Specimen dimensions 0. 3 x 0. 375 x 5 in.; obtained from National Carbon Co.; taken from 18 in. dia, 17 in. long block; bulk density 1.87 g cm^{-3} at room temperature; specific resistance at room temperature with grain 12. 72 x 10^{-4} ohm-cm, across grain 21. 54 x 10^{-4} ohm-cm; average data over several runs; expansion measured with grain.
6	371	Dull, R. B.	1964	T	293-3073	Block No. 200	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 2 in.; expansion measured with grain.
7*	371	Dull, R. B.	1964	O	293-373	Block No. 200	Specimen taken from same block as above specimen; specimen dimensions 0. 3 x 0. 375 x 5 in.; expansion measured across grain.
8	371	Dull, R. B.	1964	T	293-3073	Block No. 200	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured across grain.
9*	375	Turner, J. H. and Carter, M. B.	1964		293, 373		Specimen 0. 50 x 0. 50 x 1 in.; expansion measured with grain.
10*	375	Turner, J. H. and Carter, M. B.	1964		293, 373		The above specimen; expansion measured across grain.
11	638	Fitzer, E.	1971	L	293-1273		Petroleum-coke base graphite, fabricated by molding and pressure curing in cylindrical shapes; 18 in. diameter, 5 in. thick; density 1.88 g cm^{-3}; grain size 0.015 in.; porosity 16-17%; process temperature 3073 K; expansion measured with grain by participant No. 6.
12	638	Fitzer, E.	1971	L	293-1273		The above specimen; expansion measured across grain.
13	638	Fitzer, E.	1971	L	293-1273		Similar to the above specimen; expansion measured with grain by participant No. 8.
14*	638	Fitzer, E.	1971	L	293-1273		The above specimen; expansion measured across grain.
15	638	Fitzer, E.	1971	L	293-1273		Similar to the above specimen; expansion measured with grain by participant No. 15.
16*	638	Fitzer, E.	1971	L	293-1273		The above specimen; expansion measured across grain.
17*	638	Fitzer, E.	1971	L	293-1173		*Similar to the above specimen; expansion measured with grain by participant* No. 29.
18	638	Fitzer, E.	1971	L	293-1173		The above specimen; expansion measured across grain.
19*	638	Fitzer, E.	1971	L	293-1273		Similar to the above specimen; expansion measured with grain by participant No. 45.
20*	638	Fitzer, E.	1971	L	293-1273		The above specimen; expansion measured across grain.

* Not shown in figure.

SPECIFICATION TABLE 23. THERMAL LINEAR EXPANSION OF GRADE RVD GRAPHITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
21	644	Fitzer, E.	1972	L	293-1573		Specimen produced by Union Carbide Corp., N.Y., N.Y.; molded graphite having bulk density of 1.90 g/cc; expansion measured across grain by participant No. 5.
22	644	Fitzer, E.	1972	L	293-1573		The above specimen; expansion measured with grain.
23	644	Fitzer, E.	1972	L	293-1873		Similar to the above specimen; expansion measured across grain by participant No. 8.
24	644	Fitzer, E.	1972	L	293-1673		The above specimen; expansion measured with grain.
25	644	Fitzer, E.	1972	L	293-2673		Similar to the above specimen; expansion measured across grain.
26	644	Fitzer, E.	1972	T	293-2773		Similar to the above specimen; expansion measured across grain by participant No. 39.
27	644	Fitzer, E.	1972	T	293-2773		The above specimen; expansion measured with grain.

DATA TABLE 23. THERMAL LINEAR EXPANSION OF GRADE RVD GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
373	0.013
CURVE 2	
293	0.000*
773	0.115
1273	0.298
1770	0.502
2273	0.753
2673	1.016
3073	1.299
CURVE 3	
293	0.000*
373	0.027
CURVE 4	
293	0.000*
773	0.190
1273	0.437
1773	0.691
2673	1.058
3073	1.899
CURVE 5*	
293	0.000
373	0.014
CURVE 6	
293	0.000*
773	0.149
1273	0.298*
1773	0.479
2273	0.765
2673	1.017*
3073	1.272
CURVE 7*	
293	0.000
373	0.028

T	$\Delta L/L_0$
CURVE 8	
293	0.000*
773	0.197*
1273	0.435*
1773	0.720
2273	1.094
2673	1.491
3073	1.932
CURVE 9*	
293	0.00
373	0.01
CURVE 10*	
293	0.00
373	0.03
CURVE 11	
293	0.000*
573	0.107
673	0.146
773	0.189*
873	0.234
973	0.280
1073	0.329
1173	0.380
1273	0.433*
CURVE 12	
293	0.000*
573	0.096
673	0.133
773	0.173
873	0.215
973	0.259
1073	0.305
1173	0.352
1273	0.403
CURVE 13	
293	0.000*
573	0.098*

T	$\Delta L/L_0$
CURVE 13 (cont.)	
673	0.142*
773	0.189*
873	0.238*
973	0.289
1073	0.343
1173	0.396
1273	0.468
CURVE 14*	
293	0.000
573	0.088
673	0.129
773	0.174
873	0.222
973	0.270
1073	0.321
1173	0.375
1273	0.430
CURVE 15	
293	0.000*
373	0.040*
473	0.060*
573	0.100*
673	0.150*
773	0.200*
873	0.230*
973	0.280*
1073	0.330*
1173	0.370
1273	0.420
CURVE 16*	
293	0.000
473	0.07
573	0.110
673	0.150
773	0.195
873	0.220
973	0.264
1073	0.318
1173	0.38
1273	0.43

T	$\Delta L/L_0$
CURVE 17*	
293	0.000
373	0.022
473	0.056
573	0.094
673	0.135
773	0.178
873	0.222
973	0.267
1073	0.300
1173	0.356
CURVE 18	
293	0.000*
373	0.018*
473	0.049
573	0.082
673	0.119
773	0.156*
873	0.195
973	0.235
1073	0.277
1173	0.321
CURVE 19*	
293	0.000
373	0.023
473	0.058
573	0.096
673	0.137
773	0.181
873	0.229
973	0.276
1073	0.327
1173	0.382
1273	0.439
CURVE 20*	
293	0.000
373	0.023
473	0.054
573	0.094
673	0.129
773	0.171

T	$\Delta L/L_0$
CURVE 20 (cont.)*	
873	0.216
973	0.262
1073	0.313
1173	0.366
1273	0.420
CURVE 21	
293	0.000*
473	0.070
573	0.100*
673	0.150*
773	0.185*
873	0.230*
973	0.278*
1073	0.325*
1173	0.368*
1273	0.420*
1373	0.463
1473	0.512
1573	0.560
CURVE 22	
293	0.000*
573	0.060
673	0.085
773	0.110*
873	0.135
973	0.170
1073	0.202
1173	0.245
1273	0.280
1373	0.325
1473	0.360
1573	0.420
CURVE 23	
293	0.000*
473	0.062*
573	0.101*
673	0.145*
773	0.190*
873	0.235*
973	0.281*

T	$\Delta L/L_0$
CURVE 23 (cont.)	
1073	0.335*
1173	0.377*
1273	0.430*
1373	0.474
1473	0.522
1573	0.572
1673	0.628
1773	0.680
1873	0.740
CURVE 24	
293	0.000*
573	0.065*
673	0.087*
773	0.110*
873	0.136*
973	0.172*
1073	0.198
1173	0.240
1273	0.275*
1373	0.320
1473	0.354
1573	0.410*
1673	0.459
CURVE 25	
293	0.000*
473	0.070*
573	0.105*
673	0.155*
773	0.200*
873	0.242
973	0.290*
1073	0.333
1173	0.380
1273	0.430
1373	0.520
1473	0.565
1573	0.620
1673	0.670
1773	0.730*
1873	0.780
1973	0.900
2073	0.970

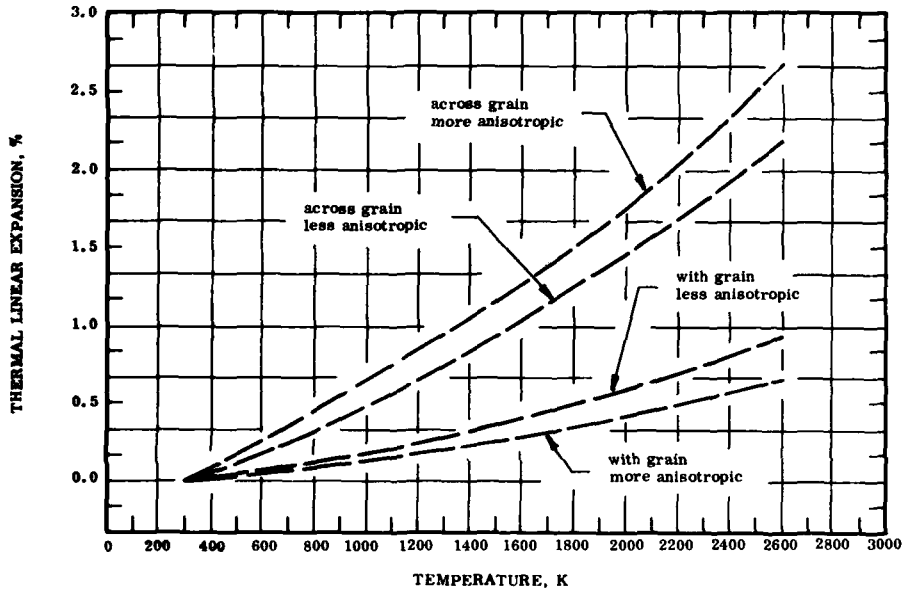
* Not shown in figure.

DATA TABLE 23. THERMAL LINEAR EXPANSION OF GRADE RVD GRAPHITE (continued)

T	$\Delta L/L_0$
CURVE 25 (cont.)	
2173	1.040
2273	1.100*
2373	1.180
2473	1.260
2573	1.340
2673	1.440
CURVE 26	
293	0.000*
1773	0.673
1873	0.748
1973	0.823
2073	0.900
2173	0.980
2273	1.065
2373	1.150
2473	1.230
2573	1.317
2673	1.403
2773	1.500
CURVE 27	
293	0.000*
1773	0.480
1873	0.535
1973	0.590
2073	0.648
2173	0.707
2273	0.774
2373	0.845
2473	0.917
2573	0.993
2673	1.070
2773	1.151

* Not shown in figure.

FIGURF AND TABLE NO. 24R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE ZTA GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	More Anisotropic			
	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	9.0	0.000	1.3
400	0.096	9.0	0.014	1.4
600	0.277	9.1	0.046	1.7
800	0.461	9.3	0.083	2.0
1000	0.650	9.6	0.126	2.3
1200	0.848	10.1	0.174	2.6
1400	1.056	10.7	0.228	2.8
1600	1.278	11.5	0.287	3.1
1800	1.516	12.3	0.351	3.3
2000	1.773	13.3	0.419	3.5
2200	2.051	14.5	0.492	3.7
2400	2.353	15.7	0.568	3.9
2600	2.681	17.1	0.649	4.1

	Less Anisotropic			
	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	5.5	0.000	2.3
400	0.062	6.0	0.025	2.4
600	0.189	6.8	0.075	2.6
800	0.332	7.5	0.130	2.9
1000	0.490	8.3	0.190	3.2
1200	0.662	8.9	0.256	3.5
1400	0.848	9.6	0.329	3.8
1600	1.045	10.2	0.408	4.2
1800	1.253	10.7	0.496	4.5
2000	1.472	11.2	0.591	5.0
2200	1.701	11.7	0.694	5.4
2400	1.938	12.1	0.807	5.9
2600	2.183	12.4	0.929	6.3

REMARKS

The provisional values are considered accurate to within ± 10% and are represented approximately by the following equations:

More Anisotropic

Across grain: $\Delta L/L_0 = -0.267 + 9.239 \times 10^{-4} T - 6.154 \times 10^{-8} T^2 + 5.473 \times 10^{-11} T^3$

With grain: $\Delta L/L_0 = -0.030 + 7.813 \times 10^{-5} T + 8.224 \times 10^{-8} T^2 - 4.554 \times 10^{-12} T^3$

Less Anisotropic

Across grain: $\Delta L/L_0 = -0.143 + 4.229 \times 10^{-4} T + 2.289 \times 10^{-7} T^2 - 1.823 \times 10^{-11} T^3$

With grain: $\Delta L/L_0 = -0.062 + 1.989 \times 10^{-4} T + 4.266 \times 10^{-8} T^2 + 1.054 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 10%.

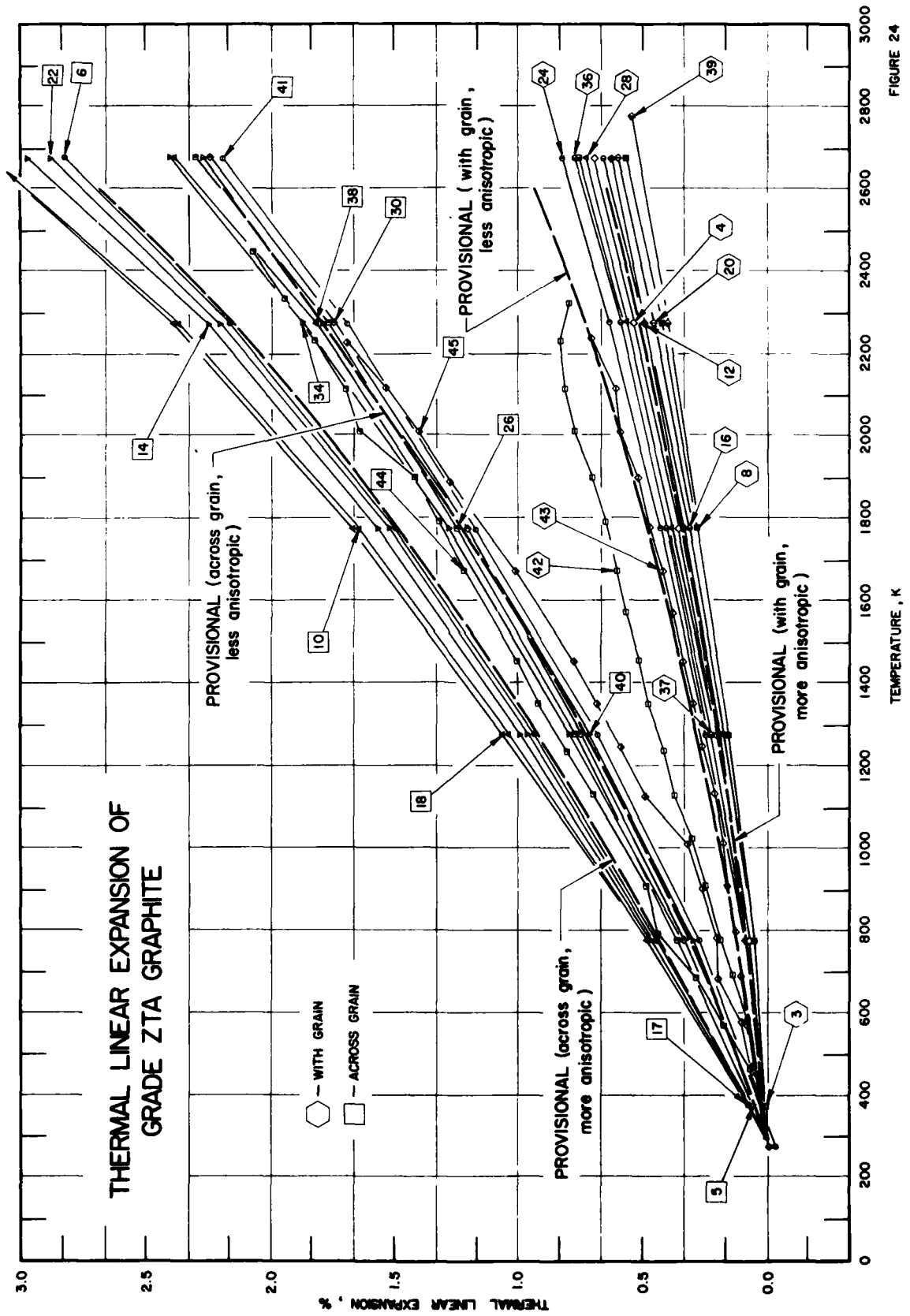

THERMAL LINEAR EXPANSION OF GRADE ZTA GRAPHITE
WITH GRAIN
ACROSS GRAIN
PROVISIONAL (across grain, less anisotropic)
PROVISIONAL (with grain, less anisotropic)
PROVISIONAL (across grain, more anisotropic)
PROVISIONAL (with grain, more anisotropic)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
0.0
0.5
1.0
1.5
2.0
2.5
3.0

FIGURE 24

SPECIFICATION TABLE 24. THERMAL LINEAR EXPANSION OF GRADE ZTA GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	377	Lowell, C. E.	1963	X	298-2640		Sample self-heated by passing current through it; lattice constant measured in c-direction in vacuo; lattice constant reported at 298 K is 6.726 Å; 6.724 Å at 293 K determined by graphical interpolation; reported error 0.1%.
2*	377	Lowell, C. E.	1963	X	6-298		The above specimen; lattice constant expansion measured in a-direction; lattice constant reported at 298 K is 2.4591 Å; 2.4591 Å at 293 K determined by graphical interpolation.
3	371	Dull, R. B.	1964	O	293, 373	Block No. 20	Specimen obtained from National Carbon Co.; dimensions 0.3 x 0.375 x 5 in.; sample taken from 14 in. diameter, 10 in. long block; average data over several runs; bulk density at room temperature 1.924 g cm^{-3}; specific resistance at room temperature parallel to grain 7.42 x 10^{-4} ohm-cm, across grain 16.18 x 10^{-4} ohm-cm; expansion measured with grain.
4	371	Dull, R. B.	1964	T	293-2673	Block No. 20	Specimen taken from same block as above specimen; specimen dimensions 0.50 x 0.50 x 5 in.; expansion measured with grain.
5	371	Dull, R. B.	1964	O	293, 373	Block No. 20	Specimen taken from same block as above specimen; specimen dimensions 0.3 x 0.375 x 5 in.; expansion measured across grain.
6	371	Dull, R. B.	1964	T	293-2673	Block No. 20	Specimen taken from same block as above specimen; specimen dimensions 0.50 x 0.50 x 5 in.; expansion measured across grain.
7*	371	Dull, R. B.	1964	O	293, 373	Block No. 23	Specimen obtained from National Carbon Co.; dimensions 0.3 x 0.375 x 5 in.; specimen taken from 14 in. diameter, 10 in. long block; average data over several runs; bulk density 1.953 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 6.91 x 10^{-4} ohm-cm, across grain 23.18 x 10^{-4} ohm-cm; expansion measured with grain.
8	371	Dull, R. B.	1964	T	293-2673	Block No. 23	Specimen taken from same block as above specimen; specimen dimensions 0.50 x 0.50 x 5 in.; expansion measured with grain.
9*	371	Dull, R. B.	1964	O	293, 373	Block No. 23	Specimen taken from same block as above specimen; specimen dimensions 0.3 x 0.375 x 5 in.; expansion measured across grain.
10	371	Dull, R. B.	1964	T	293-2673	Block No. 23	Specimen taken from same block as above specimen; specimen dimensions 0.50 x 0.50 x 5 in.; expansion measured across grain.
11*	371	Dull, R. B.	1964	O	293, 373	Block No. 111	Specimen obtained from National Carbon Co.; dimensions 0.3 x 0.375 x 5 in.; specimen taken from 14 in. diameter, 10 in. long block; average data over several runs; bulk density 1.942 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 6.70 x 10^{-4} ohm-cm, across grain 18.95 x 10^{-4} ohm-cm; expansion measured with grain.
12	371	Dull, R. B.	1964	T	293-2673	Block No. 111	Specimen taken from same block as above specimen; specimen dimensions 0.50 x 0.50 x 5 in.; expansion measured with grain.
13*	371	Dull, R. B.	1964	O	293, 373	Block No. 111	Specimen taken from same block as above specimen; specimen dimensions 0.3 x 0.375 x 5 in.; expansion measured across grain.
14	371	Dull, R. B.	1964	T	293-2673	Block No. 111	Specimen taken from same block as above specimen; specimen dimensions 0.50 x 0.50 x 5 in.; expansion measured across grain.

* Not shown in figure.

SPECIFICATION TABLE 24. THERMAL LINEAR EXPANSION OF GRADE ZTA GRAPHITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
15*	371	Dull, R. B.	1964	O	293, 373	Block No. 153	Specimen obtained from National Carbon Co.; dimensions 0. 3 x 0. 375 x 5 in.; specimen taken from 14 in. diameter, 10 in. long block; average data over several runs; bulk density 1. 955 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 6. 87 x 10^{-4} ohm-cm, across grain 22. 04 x 10^{-4} ohm-cm; expansion measured with grain.
16	371	Dull, R. B.	1964	T	293-2673	Block No. 153	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured with grain.
17	371	Dull, R. B.	1964	O	293, 373	Block No. 153	Specimen taken from same block as above specimen; specimen dimensions 0. 3 x 0. 375 x 5 in.; expansion measured across grain.
18	371	Dull, R. B.	1964	T	293-2673	Block No. 153	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured across grain.
19*	371	Dull, R. B.	1964	O	293, 373	Block No. 159	Specimen obtained from National Carbon Co.; dimensions 0. 3 x 0. 375 x 5 in.; specimen taken from 14 in. diameter, 10 in. long block; average data over several runs; bulk density 1. 923 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 7. 07 x 10^{-4} ohm-cm, across grain 22. 67 x 10^{-4} ohm-cm; expansion measured with grain.
20	371	Dull, R. B.	1964	T	293-2673	Block No. 159	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured with grain.
21*	371	Dull, R. B.	1964	O	293, 373	Block No. 159	Specimen taken from same block as above specimen; specimen dimensions 0. 3 x 0. 375 x 5 in.; expansion measured across grain.
22	371	Dull, R. B.	1964	T	293-2673	Block No. 159	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured across grain.
23*	371	Dull, R. B.	1964	O	293, 373	Block No. H-363	Specimen obtained from National Carbon Co.; dimensions 0. 3 x 0. 375 x 5 in.; specimen taken from 8. 50 in. diameter, 11 in. long block; average data over several runs; bulk density 1. 92 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 7. 76 x 10^{-4} ohm-cm, across grain 16. 45 x 10^{-4} ohm-cm; expansion measured with grain.
24	371	Dull, R. B.	1964	T	293-2673	Block No. H-363	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured with grain.
25*	371	Dull, R. B.	1964	O	293, 373	Block No. H-363	Specimen taken from same block as above specimen; specimen dimensions 0. 3 x 0. 375 x 5 in.; expansion measured across grain.
26	371	Dull, R. B.	1964	T	293-2673	Block No. H-363	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured across grain.
27*	371	Dull, R. B.	1964	O	293, 373	Block No. K-366	Specimen obtained from National Carbon Co.; dimensions 0. 3 x 0. 375 x 5 in.; specimen taken from 8. 50 in. diameter, 11 in. long block; average data over several runs; bulk density 1. 93 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 7. 54 x 10^{-4} ohm-cm, across grain 15. 84 x 10^{-4} ohm-cm; expansion measured with grain.
28	371	Dull, R. B.	1964	T	293-2673	Block No. K-366	Specimen taken from same block as above specimen; specimen dimensions 0. 50 x 0. 50 x 5 in.; expansion measured with grain.
29*	371	Dull, R. B.	1964	O	293, 373	Block No. K-366	Specimen taken from same block as above specimen; specimen dimensions 0. 3 x 0. 375 x 5 in.; expansion measured across grain.

* Not shown in figure.

SPECIFICATION TABLE 24. THERMAL LINEAR EXPANSION OF GRADE ZTA GRAPHITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
30	371	Dull, R. B.	1964	T	293-2673	Block No. K-366	Specimen taken from same block as above specimen; specimen dimensions 0.50 x 0.50 x 5 in.; expansion measured across grain.
31*	371	Dull, R. B.	1964	O	293, 373	Block No. N-367	Specimen obtained from National Carbon Co.; dimensions 0.3 x 0.375 x 5 in.; specimen taken from 8.50 in. diameter, 11 in. long block; average data over several runs; bulk density 1.95 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 6.66 x 10^{-4} ohm-cm, across grain 15.82 x 10^{-4} ohm-cm; expansion measured with grain.
32*	371	Dull, R. B.	1964	T	293-2673	Block No. N-367	Specimen taken from same block as above specimen; specimen dimensions 0.50 x 0.50 x 5 in.; expansion measured with grain.
33*	371	Dull, R. B.	1964	O	293, 373	Block No. N-367	Specimen taken from same block as above specimen; specimen dimensions 0.3 x 0.375 x 5 in.; expansion measured across grain.
34	371	Dull, R. B.	1964	T	293-2673	Block No. N-367	Specimen taken from same block as above specimen; specimen dimensions 0.50 x 0.50 x 5 in.; expansion measured across grain.
35*	371	Dull, R. B.	1964	O	293, 373	Block No. 373	Specimen dimensions 0.3 x 0.375 x 5 in.; specimen taken from 8.50 in. diameter, 11 in. long block; average data over several runs; bulk density 1.94 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 7.42 x 10^{-4} ohm-cm, across grain 16.18 x 10^{-4} ohm-cm; expansion measured with grain.
36	371	Dull, R. B.	1964	T	293-2673	Block No. 373	Specimen taken from same block as above specimen; specimen dimensions 0.50 x 0.50 x 5 in.; expansion measured with grain.
37	371	Dull, R. B.	1964	O	293-2673	Block No. 373	Specimen taken from same block as above specimen; specimen dimensions 0.3 x 0.375 x 5 in.; expansion measured with grain.
38	371	Dull, R. B.	1964	T	293-2673	Block No. 373	Specimen taken from same block as above specimen; specimen dimensions 0.50 x 0.50 x 5 in.; expansion measured across grain.
39	395	Wagner, P. and Dauelsberg, L. B.	1967	L	273-2773		Expansion measured perpendicular to force applied during molding and hot-working processes; zero-point correction of -0.003% determined by graphical interpolation.
40	395	Wagner, P. and Dauelsberg, L. B.	1967	L	273-2677		Expansion measured parallel to force applied during molding and hot-working processes; zero-point correction of -0.013% determined by graphical interpolation.
41	395	Wagner, P. and Dauelsberg, L. B.	1967	L	2677-273		The above specimen; expansion measured with decreasing temperature after specimen underwent permanent elongation while remaining 30 min. at 2573 K; dilatation effect due to elongation, not normal dilatation; zero-point correction of -0.120% determined by graphical interpolation.
42	175	Valentich, J.	1969	L	273-2321		Expansion measured with grain with increasing temperature in vacuum; zero-point correction of -0.005% determined by graphical interpolation.
43	175	Valentich, J.	1969	L	2236-450		The above specimen; expansion measured with decreasing temperature; zero-point correction of 0.026% determined by graphical extrapolation.
44	175	Valentich, J.	1969	L	358-2448		Expansion measured across grain with increasing temperature; zero-point correction of -0.088% determined by graphical extrapolation.

* Not shown in figure.

SPECIFICATION TABLE 24. THERMAL LINEAR EXPANSION OF GRADE ZTA GRAPHITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
45	175	Valentich, J.	1969	L	2227-352		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.046% determined by graphical extrapolation.
46*	375	Turner, J. H. and Carter, M. B.	1964		293, 373		Specimen 0.50 x 0.50 x 1 in.; expansion measured with grain.
47*	375	Turner, J. H. and Carter, M. B.	1964		293, 373		Similar to the above specimen; expansion measured across grain.

* Not shown in figure.

DATA TABLE 24. THERMAL LINEAR EXPANSION OF GRADE ZTA GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
6	-0.506*
78	-0.476*
193	-0.266
293	0.000
298	0.030
1041	1.606
1091	1.874
1154	1.755
1280	2.409
1291	2.201
1388	2.796
1507	2.915
1520	3.183
1649	3.331*
1761	3.956*
1764	3.926*
1812	4.105*
1866	4.224*
1890	4.462*
1970	4.729*
2011	4.937*
2030	4.908*
2067	4.908*
2088	4.908*
2114	5.086*
2176	5.116*
2185	5.235*
2206	5.562*
2247	5.413*
2271	5.532*
2282	5.354*
2300	5.681*
2340	5.711*
2370	5.919*
2388	6.008*
2422	6.306*
2467	6.484*
2529	6.722*
2580	7.019*
2642	7.019*
CURVE 2*	
6	0.1016
78	0.1138
193	0.0203
298	0.0000

T	$\Delta L/L_0$
CURVE 3	
293	0.000*
373	0.005
CURVE 4	
293	0.000*
773	0.079
1273	0.206
1773	0.363
2273	0.539
2673	0.700
CURVE 5	
293	0.000*
373	0.064
CURVE 6	
293	0.000*
773	0.447
1273	0.936
1773	1.493
2273	2.170
2673	2.837
CURVE 7*	
293	0.000
373	0.004
CURVE 8	
293	0.000*
773	0.058
1273	0.159
1773	0.286
2273	0.430
2673	0.566
CURVE 9*	
293	0.000
373	0.077

T	$\Delta L/L_0$
CURVE 10	
293	0.000*
773	0.486
1273	1.043
1773	1.646
2273	2.372
2673	3.139*
CURVE 11*	
293	0.000
373	0.005
CURVE 12	
293	0.000*
773	0.084
1273	0.199
1773	0.343
2273	0.497
2673	0.633
CURVE 13*	
293	0.000
373	0.067
CURVE 14	
293	0.000*
773	0.473
1273	0.994
1773	1.570
2273	2.257
2673	2.982
CURVE 15*	
293	0.000
373	0.006
CURVE 16	
293	0.000*
773	0.052*
1273	0.172
1773	0.325
2273	0.507*
2673	0.666

T	$\Delta L/L_0$
CURVE 17	
293	0.000*
373	0.075
CURVE 18	
293	0.000*
773	0.493*
1273	1.062
1773	1.674
2273	2.392
2673	3.139*
CURVE 19*	
293	0.000
373	0.005
CURVE 20	
293	0.000*
773	0.068*
1273	0.173*
1773	0.303*
2273	0.455
2673	0.605
CURVE 21*	
293	0.000
373	0.074
CURVE 22	
293	0.000*
773	0.458*
1273	0.957
1773	1.524
2273	2.204
2673	2.896
CURVE 23*	
293	0.000
373	0.007

T	$\Delta L/L_0$
CURVE 24	
293	0.000*
773	0.106*
1273	0.258
1773	0.431
2273	0.639
2673	0.825
CURVE 25*	
293	0.000
373	0.052
CURVE 26	
293	0.000*
773	0.364
1273	0.776
1773	1.256
2273	1.766
2673	2.304
CURVE 27*	
293	0.000
373	0.008
CURVE 28	
293	0.000*
773	0.085*
1273	0.222*
1773	0.388
2273	0.566
2673	0.730
CURVE 29*	
293	0.000
373	0.053
CURVE 30	
293	0.000*
773	0.346
1273	0.754
1773	1.204
2273	1.744
2673	2.246

T	$\Delta L/L_0$
CURVE 31*	
293	0.000
373	0.006
CURVE 32*	
293	0.000
773	0.079
1273	0.208
1773	0.370
2273	0.546
2673	0.704
CURVE 33*	
293	0.000
373	0.057
CURVE 34	
293	0.000*
773	0.349*
1273	0.794
1773	1.283
2273	1.865
2673	2.410
CURVE 35*	
293	0.000
373	0.008
CURVE 36	
293	0.000*
773	0.098*
1273	0.241*
1773	0.411
2273	0.597
2673	0.771
CURVE 37	
293	0.000*
373	0.057*
773	0.092*
1273	0.232
1773	0.400*
2273	0.587*
2673	0.758

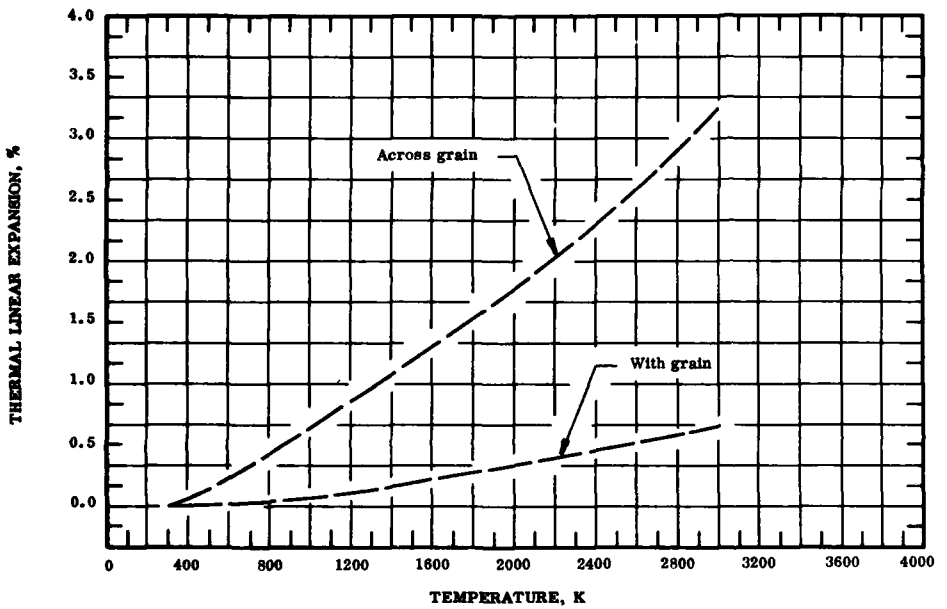
* Not shown in figure.

DATA TABLE 24. THERMAL LINEAR EXPANSION OF GRADE ZTA GRAPHITE (continued)

T	$\Delta L/L_0$
CURVE 38	
293	0.000*
373	0.055*
773	0.366*
1273	0.797*
1773	1.276*
2273	1.827
2673	2.396
CURVE 39	
273	-0.003
773	0.067*
1273	0.161*
1773	0.277*
2273	0.404
2773	0.546
CURVE 40	
273	.013*
773	0.367
1273	0.726
1773	1.216*
2273	1.787
2677	2.276
CURVE 41	
2677	2.198
2273	1.722
1773	1.177
1273	0.690
773	0.284
273	-0.030
CURVE 42	
273	-0.005*
289	-0.002*
360	0.026
468	0.061
581	0.086
691	0.142
793	0.195
907	0.251
1021	0.310
1129	0.377
1235	0.426
1349	0.479
1457	0.525
1568	0.570
1677	0.613
1786	0.652
1896	0.718
2008	0.774
2116	0.816
2227	0.831
2321	0.795
CURVE 43	
2236	0.714
2115	0.619
2005	0.598
1896	0.520
1779	0.472
1674	0.429
1566	0.386
1451	0.345
1348	0.302
1244	0.265
1132	0.220
1012	0.173
906	0.159
797	0.131
688	0.117
572	0.089
450	0.050
CURVE 44	
358	0.027*
463	0.070
569	0.175
685	0.294
789	0.442
904	0.481
1132	0.705
1233	0.809
1349	0.926
1457	1.013
1674	1.229
1786	1.330
1899	1.428
2009	1.645
2117	1.699
2231	1.829
2336	1.949
2448	2.044
CURVE 45	
2227	1.692
2119	1.538
2010	1.408
1892	1.273
1674	1.021
1456	0.779
1350	0.686
1242	0.590
1129	0.491
1008	0.333
900	0.266
776	0.200
682	0.200
576	0.116
463	0.069
352	0.024
CURVE 46*	
293	0.00
373	0.00
CURVE 47*	
293	0.00
373	0.07

* Not shown in figure.

FIGURE AND TABLE NO. 25R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE ZTB GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	9.0	0.000	0.4
400	0.097	9.1	0.006	0.6
600	0.281	9.3	0.022	1.1
800	0.470	9.6	0.048	1.5
1000	0.667	10.0	0.081	1.8
1200	0.871	10.4	0.121	2.2
1400	1.084	10.9	0.167	2.4
1600	1.307	11.4	0.218	2.7
1800	1.541	12.0	0.273	2.8
2000	1.786	12.6	0.332	3.0
2200	2.046	13.3	0.393	3.1
2400	2.319	14.0	0.455	3.1
2600	2.607	14.8	0.518	3.1
2800	2.913	15.7	0.580	3.1
3000	3.235	16.6	0.642	3.1

REMARKS

The provisional values are considered accurate to within ±7% and are represented approximately by the following equations:

Across grain: $\Delta L/L_0 = -0.259 + 8.743 \times 10^{-4} T + 2.920 \times 10^{-6} T^2 + 2.254 \times 10^{-11} T^3$

With grain: $\Delta L/L_0 = 0.001 - 4.169 \times 10^{-5} T + 1.406 \times 10^{-7} T^2 - 1.847 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

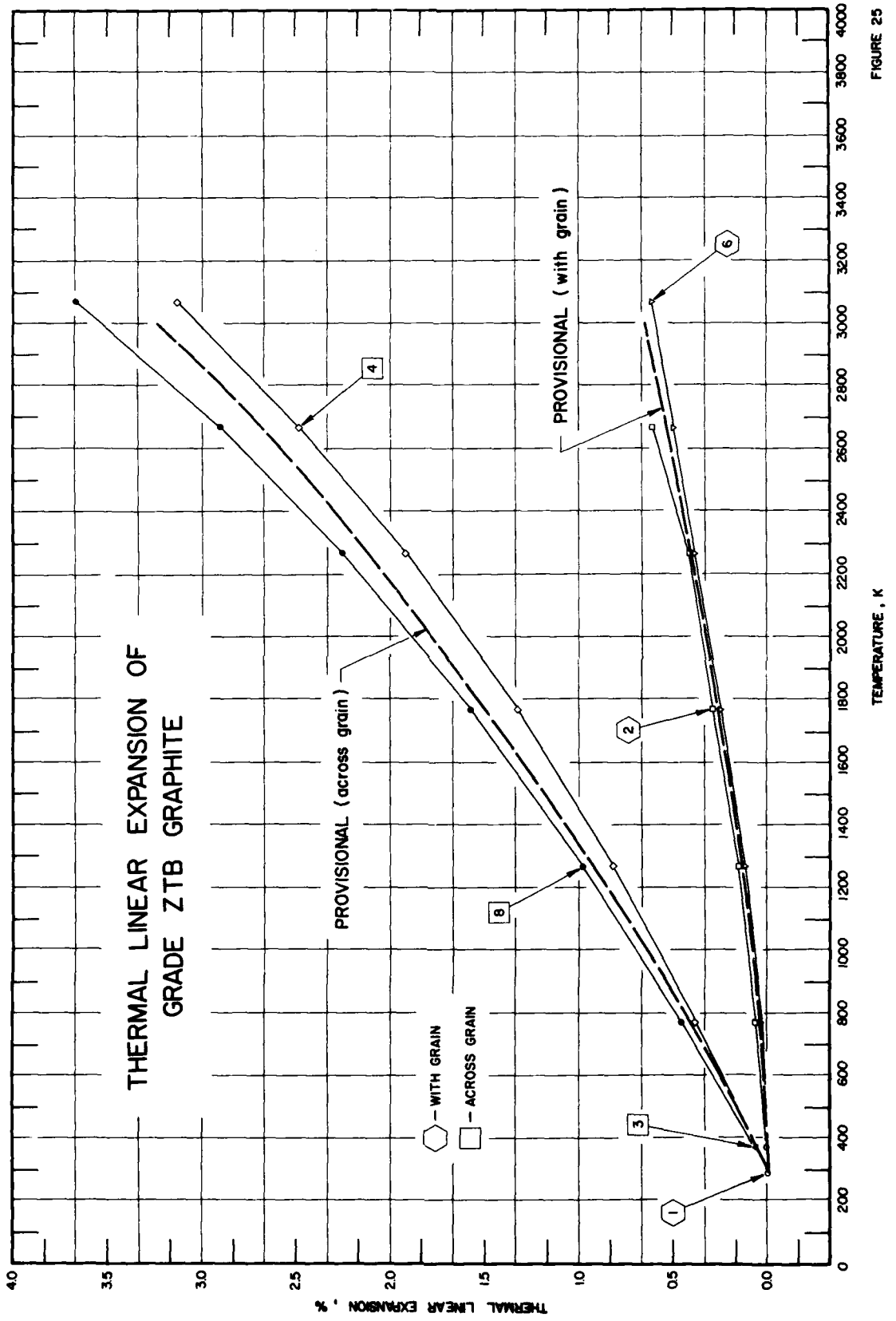

THERMAL LINEAR EXPANSION OF
GRADE ZTB GRAPHITE
PROVISIONAL (with grain)
PROVISIONAL (across grain)
WITH GRAIN
ACROSS GRAIN
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
1
2
3
4
6
8

FIGURE 25

SPECIFICATION TABLE 25. THERMAL LINEAR EXPANSION OF GRADE ZTB GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	371	Dull, R.B.	1964	O	293, 373	Block No. 1	Specimen obtained from National Carbon Co.; dimensions 0.3 x 0.375 x 5 in.; specimen taken from 8.5 in. diameter, 11 in. long block; average data over several runs; bulk density 1.97 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 6.96 x 10^{-4} ohm cm, across grain 17.81 x 10^{-4} ohm cm; expansion measured with grain.
2	371	Dull, R B.	1964	T	293-2673	Block No. 1	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; expansion measured with grain.
3	371	Dull, R.B.	1964	O	293, 373	Block No. 1	Specimen taken from same block as above specimen; specimen dimensions 0.3 x 0.375 x 5 in.; expansion measured across grain.
4	371	Dull, R.B.	1964	T	293-3073	Block No. 1	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; expansion measured across grain.
5*	371	Dull, R.B.	1964	O	293, 373	Block No. 2	Specimen obtained from National Carbon Co.; dimensions 0.3 x 0.375 x 5 in.; specimen taken from 8.5 in. diameter, 11 in. long block; average data over several runs; bulk density 1.99 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 6.43 x 10^{-4} ohm cm, across grain 21.13 x 10^{-4} ohm cm; expansion measured with grain.
6	371	Dull, R.B.	1964	T	293-3073	Block No. 2	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; expansion measured with grain.
7*	371	Dull, R.B.	1964	O	293, 373	Block No. 2	Specimen taken from same block as above specimen; specimen dimensions 0.3 x 0.375 x 5 in.; expansion measured across grain.
8	371	Dull, R.B.	1964	T	293-3073	Block No. 2	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; expansion measured across grain.
9*	375	Turner, J.H. and Carter, M.B.	1964		293, 373		Specimen 0.5 x 0.5 x 1 in.; expansion measured across grain.
10*	375	Turner, J.H. and Carter, M.B.	1964		293, 373		Similar to the above specimen; expansion measured with grain.

* Not shown in figure.

DATA TABLE 25. THERMAL LINEAR EXPANSION OF GRADE ZTB GRAPHITE

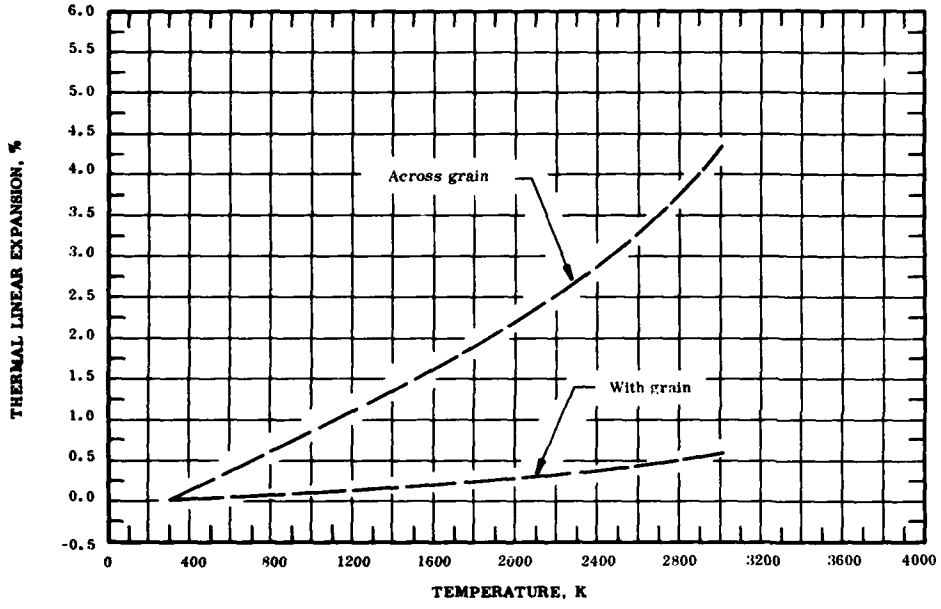
[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
373	0.005
CURVE 2	
293	0.000*
773	0.061
1273	0.161
1773	0.295
2273	0.428
2673	0.610
CURVE 3	
293	0.000*
373	0.062
CURVE 4	
293	0.000*
773	0.382
1273	0.832
1773	1.333
2273	1.924
2673	2.482
3073	3.142
CURVE 5*	
293	0.000
373	0.005
CURVE 6	
293	0.000*
773	0.041
1273	0.128
1773	0.250
2273	0.394
2673	0.506
3073	0.614

T	$\Delta L/L_0$
CURVE 7*	
293	0.000
373	0.076
CURVE 8	
293	0.000*
773	0.464
1273	0.986
1773	1.578
2273	2.256
2673	2.904
3073	3.674
CURVE 9*	
293	0.000
373	0.078
CURVE 10*	
293	0.000
373	0.004

* Not shown in figure.

FIGURE AND TABLE NO. 26R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRADE ZTC GRAPHITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Across grain		With grain	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	13.1	0.000	1.3
400	0.143	13.1	0.013	1.3
600	0.397	13.1	0.037	1.3
800	0.640	13.1	0.061	1.3
1000	0.876	13.2	0.085	1.3
1200	1.113	13.2	0.111	1.4
1400	1.356	13.2	0.139	1.5
1600	1.612	13.2	0.172	1.7
1800	1.887	14.3	0.208	2.0
2000	2.187	15.7	0.250	2.3
2200	2.518	17.4	0.299	2.6
2400	2.886	19.5	0.355	3.0
2600	3.298	21.8	0.419	3.4
2800	3.760	24.4	0.493	3.9
3000	4.277	27.4	0.577	4.5

REMARKS

The provisional values are considered accurate to within ±7% and are represented approximately by the following equations;

Across grain: $\Delta L/L_0 = -0.426 + 1.555 \times 10^{-3}\ T - 3.809 \times 10^{-7}\ T^2 + 1.284 \times 10^{-10}\ T^3$

With grain: $\Delta L/L_0 = -0.039 + 1.438 \times 10^{-4}\ T - 3.963 \times 10^{-8}\ T^2 + 2.007 \times 10^{-11}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

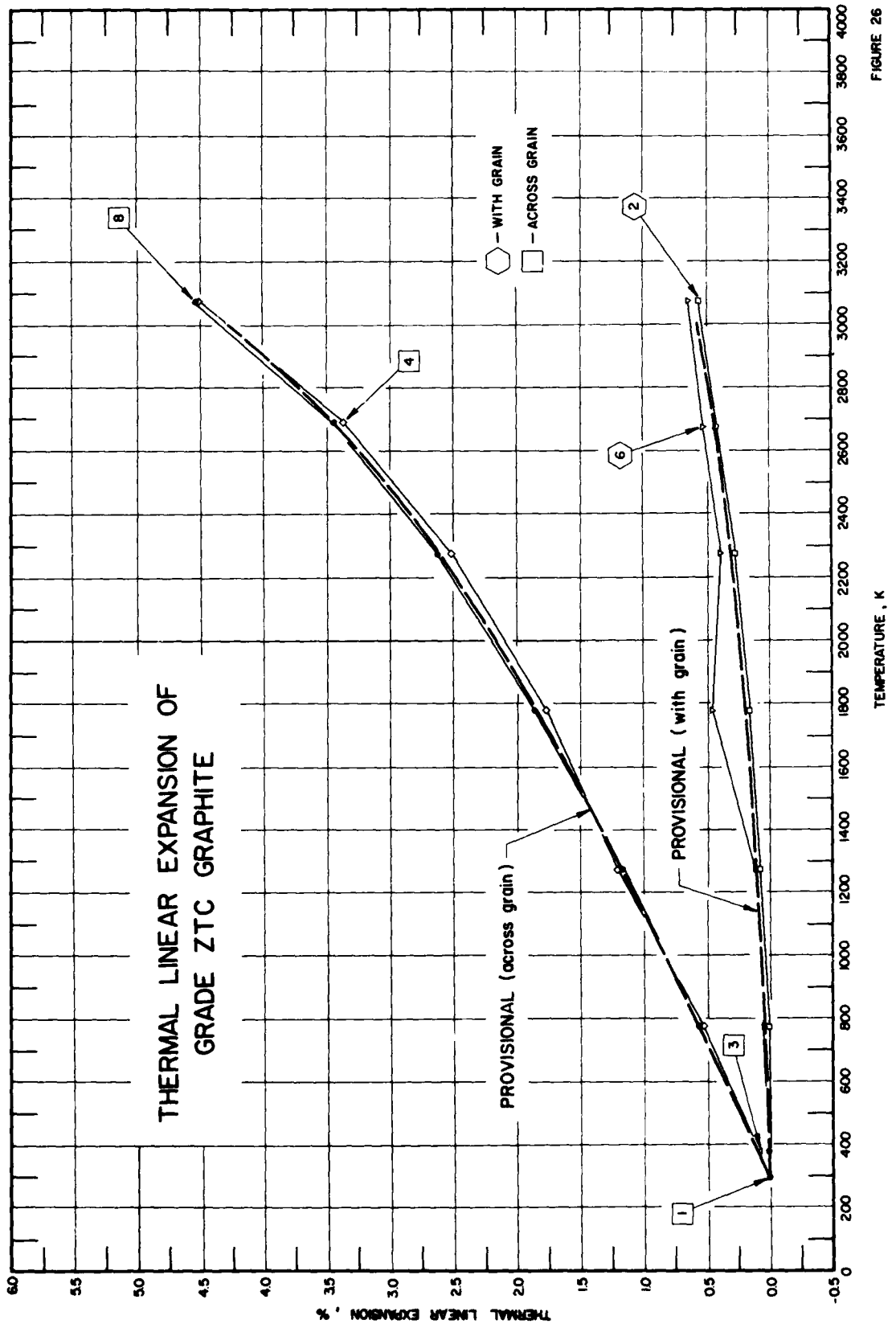

THERMAL LINEAR EXPANSION OF
GRADE ZTC GRAPHITE
WITH GRAIN
ACROSS GRAIN
PROVISIONAL (across grain)
PROVISIONAL (with grain)
1
2
3
4
6
8
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000

FIGURE 26

SPECIFICATION TABLE 26. THERMAL LINEAR EXPANSION OF GRADE ZTC GRAPHITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	371	Dull, R.B.	1964	O	293, 373	Block No. 1	Specimen obtained from National Carbon Co.; dimensions 0.3 x 0.375 x 5 in.; specimen taken from 8.5 in. diameter, 11 in. long block; bulk density 1.92 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 7.15 x 10^{-4} ohm cm, across grain 11.00 x 10^{-4} ohm cm; expansion measured with grain; average data over several runs.
2	371	Dull, R.B.	1964	T	293-3073	Block No. 1	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; expansion measured with grain.
3	371	Dull, R.B.	1964	O	293, 373	Block No. 1	Specimen taken from same block as above specimen; specimen dimensions 0.3 x 0.375 x 5 in.; expansion measured across grain.
4	371	Dull, R.B.	1964	T	293-3073	Block No. 1	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; expansion measured across grain.
5*	371	Dull, R.B.	1964	O	293, 373	Block No. 2	Specimen obtained from National Carbon Co.; dimensions 0.3 x 0.375 x 5 in.; specimen taken from 8.5 in. diameter, 11 in. long block; average data over several runs; bulk density 1.94 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 6.90 x 10^{-4} ohm cm, across grain 13.21 x 10^{-4} ohm cm; expansion measured with grain.
6	371	Dull, R.B.	1964	T	293-3073	Block No. 2	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; expansion measured with grain.
7*	371	Dull, R.B.	1964	O	293, 373	Block No. 2	Specimen taken from same block as above specimen; specimen dimensions 0.3 x 0.375 x 5 in.; expansion measured across grain.
8	371	Dull, R.B.	1964	T	293-3073	Block No. 2	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; expansion measured across grain.

DATA TABLE 26. THERMAL LINEAR EXPANSION OF GRADE ZTC GRAPHITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 3		CURVE 5*		CURVE 7*	
293	0.000	293	0.000*	293	0.000	293	0.000
373	0.014	373	0.084	373	0.021	373	0.082
CURVE 2		CURVE 4		CURVE 6		CURVE 8	
293	0.000*	293	0.000*	293	0.000*	293	0.000*
773	0.014	773	0.538	773	0.053	773	0.558
1273	0.083	1273	1.222	1273	0.137	1273	1.168
1773	0.170	1773	1.779	1773	0.454	1773	1.862
2273	0.287	2273	2.513	2273	0.399	2273	2.622
2673	0.432	2673	3.381	2673	0.535	2673	3.440
3073	0.577	3073	4.514	3073	0.650	3073	4.538

* Not shown in figure.

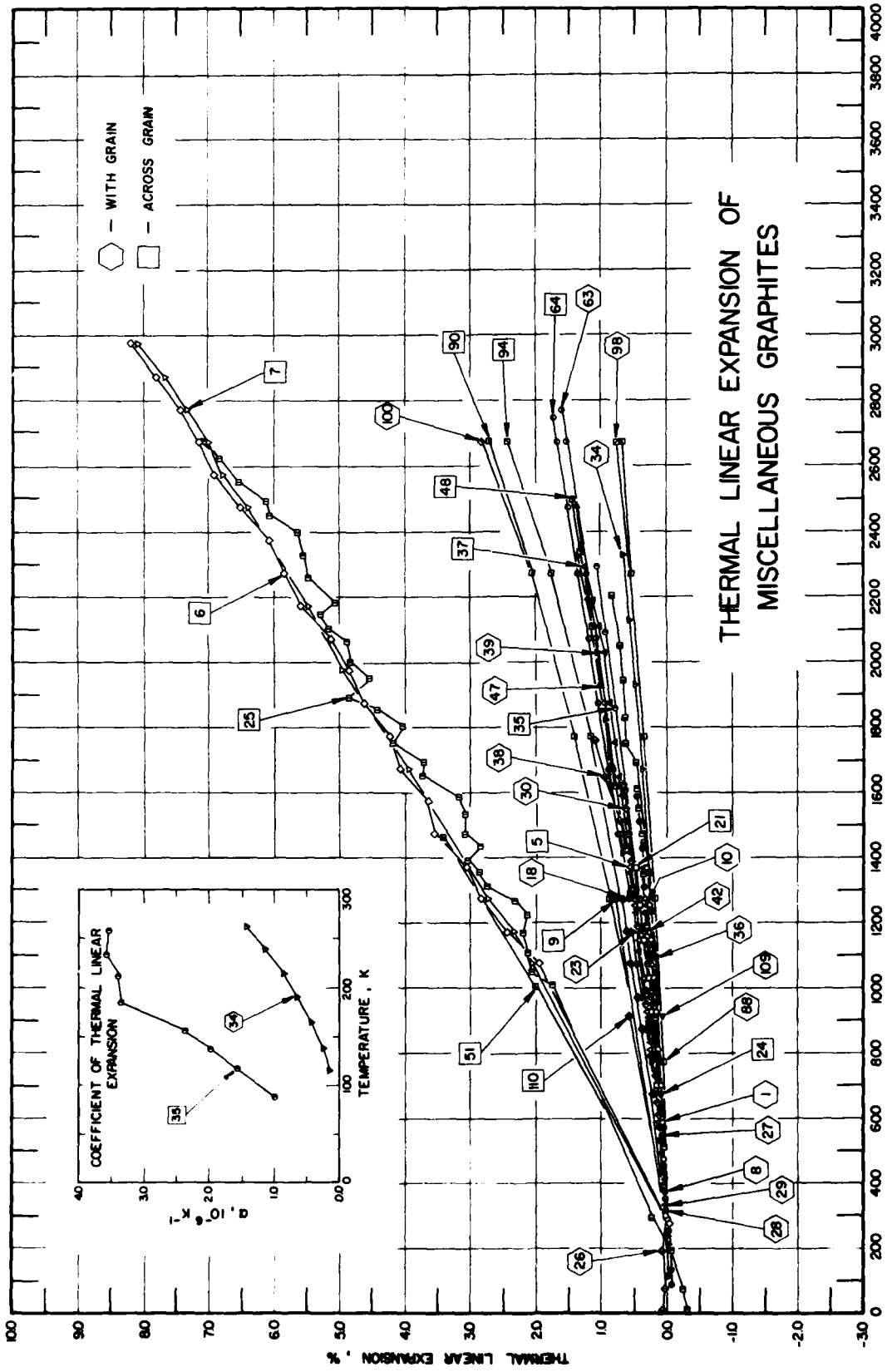

THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES
— WITH GRAIN
— ACROSS GRAIN
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K

FIGURE 27

SPECIFICATION TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	368	Allen, R.D.	1959	L	300-1367	896G Grade Graphite; Block No. 0701	Specimen obtained from Speer Carbon Co.; dimension 0.25 in. diameter and 2 in. long; max. filler particle size 0.033 in.; petroleum coke and cool tar pitch mixed together, extruded, and graphitized at above 2533 K; heated in an atm of helium with a heating rate of 555 K per hr, soaked 0.5 hr at 1366 K; expansion measured parallel to the grain direction.
2	368	Allen, R.D.	1959	L	300-1367	896G Grade Graphite; Block No. 0701	The above specimen except expansion measured perpendicular to the grain direction.
3*	368	Allen, R.D.	1959	L	300-1366	942S Grade Graphite; Block No. 0201	Specimen obtained from Speer Carbon Co.; dimension 0.25 in. diameter and 2 in. long; max. filler particle size 0.033 in.; petroleum coke mixed with coal tar pitch, impregnated with coal tar pitch, extruded and graphitized at above 2533 K; heated in atm of helium with heating rate of 555 K per hr, soaked 0.5 hr at 1366 K; expansion measured parallel to the grain direction.
4*	368	Allen, R.D.	1959	L	300-1366	942S Grade Graphite; Block No. 0201	The above specimen except expansion measured perpendicular to the grain direction.
5	368	Allen, R.D.	1959	L	300-1366	942S Grade Graphite; Block No. 0201	Similar to the above specimen.
6	367	Elliott, E.S. and Richardson, J.H.	1968	X	273-3273	AGKSP Graphite	Specimen from National Carbon Co.; lattice dimension expansion measured along c-axis on first run; lattice dimension reported at 293 K is 6.740 Å.
7	367	Elliott, E.S. and Richardson, J.H.	1968	X	273-3273	AGKSP Graphite	The above specimen; lattice dimension expansion measured on second run.
8	66	General Dynamics Corp.	1960		294-1272	AGOT Graphite	Specimen density 1.6 g cm^{-3}; expansion measured parallel to extrusion axis.
9	66	General Dynamics Corp.	1960		294-1272	AGOT Graphite	Specimen density 1.6 g cm^{-3}; expansion measured perpendicular to extrusion axis.
10	368	Allen, R.D.	1959		300-1367	AGR Grade Graphite; Block No. 0301	Specimen obtained from National Carbon Co.; dimension 0.25 in. diameter and 2 in. long; max. filler particle size 0.025 in.; petroleum coke and coal tar pitch mixed together, extruded, and graphitized at 3033 K; heated in atm of helium with heating rate of 555 K per hr, soaked 0.5 hr at 1366 K; expansion measured parallel to grain direction.
11*	368	Allen, R.D.	1959		300-1367	AGR Grade Graphite; Block No. 0301	The above specimen except expansion measured perpendicular to grain direction.
12*	368	Allen, R.D.	1959		300-1367	AGR Grade Graphite; Block No. 0301	Similar to the above specimen.
13*	368	Allen, R.D.	1959		299-1367	AGX Graphite Block No. 1101 Sample 1	Specimen obtained from National Carbon Co.; dimension 0.25 in. diameter and 2 in. long; coke pitch extruded and graphitized at temperature 3033 K; specimen heated in atm of helium with heating rate 555 K per hr, and soaked 0.5 hr at 1366 K; average of 6 runs; expansion measured parallel to grain direction.

* Not shown in figure.

SPECIFICATION TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
14*	368	Allen, R.D.	1959		299-1367	AGX Graphite; Block No. 1101, Sample 2	Similar to the above specimen.
15*	368	Allen, R.D.	1959		299-1367	AGX Graphite; Block No. 1101, Sample 3	Similar to the above specimen.
16*	376	Waylett, C.E., Carter, M.B., and Spring, M.A.	1964		303,373	ATL Graphite	Specimen obtained from National Carbon Co.; molded; bulk density 1.78 g cm^{-3}; specific resistance with grain 11.30 x 10^{-4} ohm-cm, across grain 11.80 x 10^{-4} ohm-cm; expansion measured parallel to grain.
17*	376	Waylett, C.E., et al.	1964		303,373	ATL Graphite	The above specimen except expansion measured across grain.
18	369	Meyers, C. and Koyama, K.	1968	V	295-1273	B205 Carbon	Specimen cut from larger bar supplied by Great Lakes Carbon Co.; expansion measured parallel to length of bar; zero-point correction of 0.001% determined by graphical extrapolation.
19*	369	Meyers, C. and Koyama, K.	1968	V	295-1277	B205 Carbon	The above specimen; expansion measured perpendicular to length of bar; zero-point correction of 0.001% determined by graphical extrapolation.
20*	375	Turner, J.H. and Carter, M.B.	1964		293-373	Grade CA Graphite	Extruded specimen 0.5 x 0.5 x 1 in., 0.015 in. grain; bulk density 1.68 g cm^{-3}; expansion measured with grain.
21*	375	Turner, J.H. and Carter, M.B.	1964		293-373	Grade CB Graphite	Extruded specimen 0.5 x 0.5 x 1 in., 0.030 in. grain; expansion measured with grain.
22*	375	Turner, J.H. and Carter, M.B.	1964		293-373	Grade CB Graphite	Similar to the above specimen; expansion measured across grain.
23	369	Meyers, C. and Koyama, K.	1968	V	295-1273	CBN Graphite	Specimen cut from large bar supplied by Union Carbide and Chemical; expansion measured parallel to length of original bar; zero-point correction of 0.001% determined by graphical extrapolation.
24	369	Meyers, C. and Koyama, K.	1968	V	295-1273	CBN Graphite	The above specimen; expansion measured perpendicular to length.
25	377	Lowell, C.E.	1963	X	6-2679	CEP Graphite	Rod specimen 1 in. long; lampblack-base material of poor crystallinity and almost random orientation; lattice constant expansion measured along c-axis; lattice constant reported at 293 K is 6.788 Å; coefficient of thermal linear expansion also reported.
26	377	Lowell, C.E.	1963	X	6-298	CEP Graphite	The above specimen; lattice constant expansion measured along a-axis; lattice constant reported at 298 K is 2.457 Å; 2.457 Å at 293 K determined by graphical interpolation.
27	72	Fulkerson, S.D.	1959	L	313-1608	CS 312 Graphite	Specimen rod 2.54 cm x 0.64 cm diameter cut from outer periphery of log parallel to axis of extrusion; expansion measured in 1/2 atm pressure of argon gas; zero-point correction of -0.012% determined by graphical extrapolation.
28	72	Fulkerson, S.D.	1959	L	315-1612	CS 312 Graphite	Similar to the above specimen; cut from center of log parallel to axis of extrusion; zero-point correction of -0.013% determined by graphical extrapolation.
29	72	Fulkerson, S.D.	1959	L	292-1613	CS 312 Graphite	Similar to the above specimen; cut from outer periphery of log perpendicular to direction of extrusion; zero-point correction of -0.012% determined by graphical interpolation.

* Not shown in figure.

SPECIFICATION TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
30	72	Fulkerson, S.D.	1959	L	289-1625	CS 312 Graphite	Similar to the above specimen; cut from outer periphery of log perpendicular to direction of extrusion; zero-point correction of -0.017% determined by graphical interpolation.
31*	368	Allen, R.D.	1959	L	299-1366	EH Graphite	Specimen obtained from Speer Carbon Co.; dimension 0.25 in. diameter and 2 in. long; max. filler particle size 0.005; graphite flour mixed with coal tar pitch; impregnated with coal tar pitch, molded, and graphitized at above 2788 K; heated in atm of helium with heating rate 555 K per hr, soaked 0.5 hr at 1366 K, expansion measured parallel to grain direction.
32*	368	Allen, R.D.	1959	L	299-1366	EH Graphite	The above specimen except expansion measured perpendicular to grain direction.
33*	368	Allen, R.D.	1959	L	299-1366	EH Graphite	The above specimen.
34	356	Mason, I.B. and Knibbs, R.H.	1964	L	115-2327	Grade EY-9 Graphite	Expansion measured parallel to direction of extrusion.
35	356	Mason, I.B. and Knibbs, R.H.	1964	L	89-2295	Grade EY-9 Graphite	Expansion measured perpendicular to extrusion.
36	398	Worth, K. and Taylor, J.	1963		293-2202	GLI-S4 Great Lakes Impervious Graphite	Baked; expansion measured parallel to the extrusion axis in helium atm.
37	398	Worth, K. and Taylor, J.	1963		293-2294	GLI-S4 Great Lakes Impervious Graphite	Baked; expansion measured perpendicular to the extrusion axis in helium atm.
38	398	Worth, K. and Taylor, J.	1963		293-1760	Ω V5G Great Lakes Graphite	Base stock impregnated at General Atomic; baked; expansion measured transverse to the direction of extrusion in helium atm.
39	398	Worth, K. and Taylor, J.	1963		293-2324	B-2 Great Lakes end-cap Graphite	Baked; expansion measured transverse to the direction of extrusion in helium atm.
40*	369	Meyers, C. and Koyama, K.	1968	V	295-1273	H 205 Graphite	Specimen cut from large cylinder supplied by Great Lakes Carbon Co.; expansion measured parallel to length of original cylinder; zero-point correction of 0.001% determined by graphical extrapolation.
41*	369	Meyers, C. and Koyama, K.	1968	V	295-1273	H 205 Graphite	The above specimen; expansion measured perpendicular to length of original cylinder; zero-point correction of 0.001% determined by graphical extrapolation.
42	369	Meyers, C. and Koyama, K.	1968	V	295-1273	H 249 Graphite	Specimen cut from cylinder supplied by Great Lakes Carbon Co.; expansion measured parallel to length of original cylinder.
43*	369	Meyers, C. and Koyama, K.	1968	V	295-1273	H 249 Graphite	The above specimen; expansion measured perpendicular to length of original cylinder.
44*	368	Allen, R.D.	1959		299-1366	H3LM Grade Graphite	Specimen obtained from Great Lakes Co.; dimension 0.25 in. diameter and 2 in. long; petroleum coke mixed with coal tar pitch, impregnated with coal tar pitch, extruded, and graphitized at 3074.7 K; max. filler particle size 0.06 in.; heated in atm of helium with heating rate 555 K per hr; soaked 0.5 hr at 1366.3 K; expansion measured parallel to grain direction.

* Not shown in figure.

SPECIFICATION TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
45*	368	Allen, R.D.	1959		299-1366	H3LM Grade Graphite	The above specimen except measured perpendicular to grain direction.
46*	368	Allen, R.D.	1959		299-1366	H3LM Grade Graphite	Similar to the above specimen.
47	388	Illinois Institute Technology Research Institute	1966		293-2477	JTA Graphite	Specimen contains ZrB_2, SiC impurities; cut from large sample; data is average of five specimens; expansion measured with grain.
48	388	Illinois Institute Technology Research Institute	1966		293-2499	JTA Graphite	The above specimen; expansion measured across grain.
49*	369	Meyers, C. and Koyama, K.	1968	V	295-1273	MHLM Graphite	Specimen cut from large cylinder supplied by Great Lakes Carbon Co.; expansion measured along length of original cylinder.
50*	369	Meyers, C. and Koyama, K.	1968	V	295-1273	MHLM Graphite	The above specimen; expansion measured perpendicular to length of original cylinder.
51	409	Steward, E.G. and Cook, B.P.	1960	X	288-1461	Natural Ceylon Graphite	Expansion measured perpendicular to the basal plane; calculated from interlayer spacing; reported error ≤3%.
52*	401	Baskin, Y. and Meyer, L.	1955	X	78-297	Natural Graphite	Spectroscopically pure powder; obtained from National Carbon Corp. No. SP1; average thermal expansion coefficient from interlayer C-spacing data; Ni-filtered Cu radiation used.
53*	369	Meyers, C. and Koyama, K.	1968	V	295-1273	PGX Graphite	Specimen cut from large cylinder supplied by Union Carbide and Chemical Co.; expansion measured parallel to length of original cylinder.
54*	369	Meyers, C. and Koyama, K.	1968	V	295-1273	PGX Graphite	The above specimen; expansion measured perpendicular to length of original cylinder.
55*	389	Kachur, V.	1965		293-2755	P-03 Graphite	Premium-quality molded graphite, isostatically molded stock, average particle size not exceeding 0.003 in.; sample with reference length (293 K) 2.0 in.; density 1.875 g cm^{-3}; radiantly heated in helium atm.
56*	389	Kachur, V.	1965		293-2755	P-03 Graphite	Similar to the above specimen; specimen taken from sample 7.25 in. diameter and 7 in. long; density 1.84 g cm^{-3}.
57*	389	Kachur, V.	1965		293-2755	P-03 Graphite	Similar to the above specimen; axial specimen; length at room temperature 2.0 in.; density 1.87 g cm^{-3}.
58*	389	Kachur, V.	1965		293-2755	P-03 Graphite	Similar to the above specimen; axial specimen; density 1.84 g cm^{-3}.
59*	389	Kachur, V.	1965		293-1073	P-03 Graphite	Regularly molded; specimen 0.3125 in. diameter, 4.00 in. long; sample from 4 x 4 x 1.1 in. stock; expansion measured with grain direction by the Industrial Laboratory Services Corp. directed by Mr. W. D. Zeik; expansion measured by means of modified optical strain-gauge system.
60*	389	Kachur, V.	1965		293-1073	P-03 Graphite	Similar to the above specimen; specimen from 12 x 12 x 12 in. stock; expansion measured with grain direction.
61*	389	Kachur, V.	1965		293-1073	P-03 Graphite	Regularly molded stock; specimen 0.3125 in. diameter, 4.0 in. long; expansion measured by the Industrial Laboratory Service Corp. directed by Mr. W. D. Zeik; expansion measured with grain direction.

* Not shown in figure.

SPECIFICATION TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
62*	389	Kachur, V.	1965		293-1073	P-03 Graphite	Similar to the above specimen; expansion measured across grain direction.
63	392	Wagner, P. and Dauelsberg, L.B.	1968		298-2773	SX-5 Graphite	Specimen obtained from Speer Carbon Co.; expansion measured parallel to extrusion direction (X); zero-point correction of 0.0025% determined by graphical extrapolation.
64	392	Wagner, P. and Dauelsberg, L.B.	1968		298-2743	SX-5 Graphite	The above specimen; expansion measured perpendicular to extrusion direction (Z); zero-point correction of 0.0027% determined by graphical extrapolation.
65*	393	Morrison, B.H.	1968		293-3156	SX-5 Graphite	Specimen 30 in. stack, centered in 120 in. long, 6 in. diameter graphite tube resistance furnace, heated at rate of 3 to 4 C per min to 2773 K; temperature determined with pt-pt 10 Rh thermocouple from 293 to 1073 K and with optical pyrometer over remaining range, one atm of He maintained in furnace; expansion measured along X-axis.
66*	393	Morrison, B.H.	1968		293-3109	SX-5 Graphite	The above specimen; expansion measured along Y-axis.
67*	393	Morrison, B.H.	1968		293-3083	SX-5 Graphite	The above specimen; expansion measured along Z-axis.
68*	369	Meyers, C. and Koyama, K.	1968	V	295-1073	TS-574 Graphite	Specimen cut from large cylinder, impregnated with MoS_2 and Ag, supplied by Union Carbide and Chemical Co.; expansion measured along X direction.
69*	369	Meyers, C. and Koyama, K.	1968	V	295-1073	TS-574 Graphite	The above specimen; expansion measured along Y direction; zero-point correction of 0.001% determined by graphical extrapolation.
70*	369	Meyers, C. and Koyama, K.	1968	V	295-1073	TS-574 Graphite	The above specimen; expansion measured along Y direction; zero-point correction of 0.001% determined by graphical extrapolation.
71*	369	Meyers, C. and Koyama, K.	1968	V	295-1073	TS-574 Graphite	The above specimen; expansion measured along Z direction.
72*	369	Meyers, C. and Koyama, K.	1968	V	295-973	TS-835 Graphite	Specimen cut from large cylinder, obtained from Union Carbide and Chemical Co.; expansion measured parallel to length of original cylinder (Z direction); zero-point correction of 0.001% determined by graphical extrapolation.
73*	369	Meyers, C. and Koyama, K.	1968	V	295-873	TS-835 Graphite	The above specimen; expansion measured perpendicular to length (X direction); zero-point correction of 0.001% determined by graphical extrapolation.
74*	369	Meyers, C. and Koyama, K.	1968	V	295-873	TS-835 Graphite	The above specimen; expansion measured perpendicular to the two above measured directions (Y direction); zero-point correction of 0.001% determined by graphical extrapolation.
75*	377	Lowell, C.E.	1963	X	293-2600	TSX Graphite	Sample self-heated by passing current through it; lattice constant expansion measured along c-axis in vacuo; lattice constant reported at 293 K is 6.714 Å; reported error 0.1%.
76*	394	Slagle, O.D.	1969	O	1273-2670	TSX Graphite	Specimen machined in shape of standard dogbone tensile with 0.2 x 0.2 in. square test section; heated specimen to 2673 K in helium; expansion measured on first cycle; this curve is here reported using the first given temperature (1273 K) as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction of -0.103%.
77*	394	Slagle, O.D.	1969	O	2670-1273	TSX Graphite	The above specimen; expansion measured with decreasing temperature on first cycle; this curve is here reported using the first given temperature (2670 K) as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction of -1.106%.

* Not shown in figure.

SPECIFICATION TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
78*	394	Slagle, O.D.	1969	O	1273-2671	TSX Graphite	The above specimen; expansion measured with increasing temperature on second cycle; this curve is here reported using the first given temperature (1273 K) as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction of -0.103%.
79*	394	Slagle, O.D.	1969	O	2671-1273	TSX Graphite	The above specimen; expansion measured with decreasing temperature on second cycle; this curve is here reported using the first given temperature (2671 K) as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction of -1.066%.
80*	394	Slagle, O.D.	1969	O	1273-2672	TSX Graphite	The above specimen; expansion measured with increasing temperature on third cycle; this curve is here reported using the first given temperature (1273 K) as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction of -0.076%.
81*	394	Slagle, O.D.	1969	O	2672-1273	TSX Graphite	The above specimen; expansion measured with decreasing temperature on third cycle; this curve is here reported using the first given temperature :2672 K) as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction of -1.043%.
82*	394	Slagle, O.D.	1969	O	1273-2674	TSX Graphite	Similar to the above specimen; expansion measured for parallel orientation with increasing temperature on first cycle; this curve is here reported using the first given temperature (1273 K) as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction of -0.115%.
83*	394	Slagle, O.D.	1969	O	2674-1273	TSX Graphite	The above specimen; expansion measured with decreasing temperature on first cycle; this curve is here reported using the first given temperature (2674 K) as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction of -0.624%.
84*	394	Slagle, O.D.	1969	O	1275-2674	TSX Graphite	The above specimen; expansion measured with increasing temperature on second cycle; this curve is here reported using the first given temperature (1275 K) as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction of -0.136%.
85*	394	Slagle, O.D.	1969	O	2674-1275	TSX Graphite	The above specimen; expansion measured with decreasing temperature on second cycle; this curve is here reported using the first given temperature (2674 K) as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction of -0.602%.
86*	374	Anthony, F.M. and Pearl, H.A.	1960	L	300-1633	W Graphite	Siliconized silicon carbide coated specimen; 0.375 in. diameter, 3 in. long; reported error ±5%.
87*	371	Dull, R.B.	1964	O	293,373	ZTD Graphite	Specimen obtained from National Carbon Co.; dimensions 0.3 x 0.375 x 5 in.; specimen taken from 14 in. diameter, 10 in. long block; average data over several runs; bulk density 2.01 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 5.41 x 10^{-4} ohm-cm, across grain 7.88 x 10^{-4} ohm-cm; expansion measured with grain.
88	371	Dull, R.B.	1964	T	293-2673	ZTD Graphite	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; expansion measured with grain.
89*	371	Dull, R.B.	1964	O	293,373	ZTD Graphite	Specimen taken from same block as above specimen; specimen dimensions 0.3 x 0.375 x 5 in.; expansion measured across grain.
90	371	Dull, R.B.	1964	T	293-2673	ZTD Graphite	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; expansion measured across grain.
91*	371	Dull, R.B.	1964	O	293,373	ZTE Graphite	Specimen obtained from National Carbon Co.; dimensions 0.3 x 0.375 x 5 in.; specimen taken from 30 in. diameter, 23.5 in. long block; average data over several runs; bulk density 1.96 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 8.94 x 10^{-4} ohm-cm, across grain 20.40 x 10^{-4} ohm-cm; expansion measured with grain.

* Not shown in figure.

SPECIFICATION TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
92*	371	Dull, R.B.	1964	T	293-2673	ZTE Graphite	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; expansion measured with grain.
93*	371	Dull, R.B.	1964	T	293,373	ZTE Graphite	Specimen taken from same block as above specimen; specimen dimensions 0.3 x 0.375 x 5 in.; expansion measured across grain.
94	371	Dull, R.B.	1964	T	293-2673	ZTE Graphite	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; expansion measured across grain.
95*	375	Turner, J.H. and Carter, M.B.	1964		293,373	ZTE Graphite	Specimen 0.5 x 0.5 x 1 in.; expansion measured with grain.
96*	375	Turner, J.H. and Carter, M.B.	1964		293,373	ZTE Graphite	Similar to the above specimen; expansion measured across grain.
97*	371	Dull, R.B.	1964	O	293,373	ZTF Graphite	Specimen obtained from National Carbon Co.; dimensions 0.3 x 0.375 x 5 in.; specimen taken from 14 in. diameter, 11 in. long block; average data over several runs; bulk density 1.99 g cm^{-3} at room temperature; specific resistance at room temperature parallel to grain 7.24 x 10^{-4} ohm-cm, across grain 21.48 x 10^{-4} ohm-cm; expansion measured with grain.
98	371	Dull, R.B.	1964	T	293-2673	ZTF Graphite	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; expansion measured with grain.
99*	371	Dull, R.B.	1964	T	293,373	ZTF Graphite	Specimen taken from same block as above specimen; specimen dimensions 0.3 x 0.375 x 5 in.; measured across grain.
100	371	Dull, R.B.	1964	T	293-2673	ZTF Graphite	Specimen taken from same block as above specimen; specimen dimensions 0.5 x 0.5 x 5 in.; measured parallel to grain.
101*	375	Turner, J.H. and Carter, M.B.	1964		293-373	ZTF Graphite	Specimen 0.5 x 0.5 x 1 in.; expansion measured with grain.
102*	375	Turner, J.H. and Carter, M.B.	1964		293-373	ZTF Graphite	Similar to the above specimen; expansion measured across grain.
103*	401	Baskin, Y. and Meyer, L.	1955	X	78-297	Artificial Graphite	Spectroscopically pure artificial graphite; obtained from National Carbon Corp. No. SP2; average thermal expansion coefficient from interlayer C spacing data; Ni-filtered Cu radiation used.
104*	402	Nelson, J.B. and Riley, D.P.	1945	X	288-1073	Ceylon Graphite	Impurity 4.0 ash; after reducing material passed 300-mesh B.S.S. sieve; silica capillary tube of bore 0.05 cm, wall thickness of 0.003 cm filled; heated to about 1123 K for 30 min; expansion measured in c-dimension; lattice constant reported at 287.8 K is 6.6943 Å; 6.6953 Å at 293.2 K determined by graphical interpolation.
105*	402	Nelson, J.B. and Riley, D.P.	1945	X	287.8-1073	Ceylon Graphite	The above specimen; expansion measured in a-dimension of measurement A; lattice constant reported at 287.8 K is 2.45626 Å; 2.45624 Å at 293.2 K determined by graphical interpolation.
106*	402	Nelson, J.B. and Riley, D.P.	1945	X	287.8-1073	Ceylon Graphite	The above specimen; expansion measured in a-dimension of measurement B; lattice constant reported at 287.8 K is 2.45617 Å; 2.45615 Å at 293.2 K determined by graphical interpolation.
107*	404	Smith, M.G. and Imprescia, R.J.	1968	X	298,773	49 B-2 Anisotropic Graphite	80.0 GP (Py)-3 (ground pyrolytic graphite), 20.0 TP-4 (Thermax carbon black-Thermatomic Carbon Co.) of filler, 40 Varcum Binder molding at 2000 psi at 1173 K, cylinder form specimen, 2.5 to 4 in. diameter and 2.3 to 2.7 in. high; expansion measured with grain.

* Not shown in figure.

SPECIFICATION TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
108*	404	Smith, M.G. and Imprescia, R.J.	1968	X	298,773	49 B-2 Anisotropic Graphite	The above specimen except expansion measured across grain.
109	404	Smith, M.G. and Imprescia, R.J.	1968	X	298,918	50 B-1 Anisotropic Graphite	80.0 G (Na)-21 (natural graphite flakes - Southwestern Graphite Co. grade 1651), 20.0 TP-4 (Thermax carbon black - Thermatomic Carbon Co.) of filler, 20 pitch binder, molding at 1500 psi at 1173 K, cylinder form specimen, 2.5 to 4 in. diameter and 2.3 to 2.7 in. high; expansion measured with grain.
110	404	Smith, M.G. and Imprescia, R.J.	1968	X	298,918	50 B-1 Anisotropic Graphite	The above specimen except expansion measured across grain.
111*	404	Smith, M.G. and Imprescia, R.J.	1968	X	298,918	50 D-1 Anisotropic Graphite	100.0 G (Na)-21 (natural graphite flakes - Southwestern Graphite Co. grade 1651), 30 varcum binder, molding at 1000 psi at 1173 K, cylinder form specimen, 2.5 to 4 in. diameter and 2.3 to 2.7 in. high; expansion measured with grain.
112*	404	Smith, M.G. and Imprescia, R.J.	1968	X	298,918	50 D-1 Anisotropic Graphite	The above specimen except expansion measured across grain.
113*	404	Smith, M.G. and Imprescia, R.J.	1968	X	298,918	50 I-1 Anisotropic Graphite	80.0 GP (Py)-10 (ground pyrolytic graphite), 20.0 CN-3 (Needle coke flour - Carbon Products Division, Union Carbide Corp.), molding at 1000 psi at 1143 K, cylinder specimen 2.5 to 4 in. diameter and 2.3 to 2.7 in. high; expansion measured with grain.
114*	404	Smith, M.G. and Imprescia, R.J.	1968	X	298,918	50 I-1 Anisotropic Graphite	The above specimen except expansion measured across grain.
115*	407	Walker, P.L., McKinetry, H.A., and Wright, C.C.	1953	X	77-1289	Graphitized Carbon	Graphitized carbon ground in agate mortar and pestle to pass through 325-mesh screen, wetted with trace of water, about 0.2 gram placed in specimen holder by means of spatula, Cu K-α radiation used; expansion of interplanar spacing measured in N_2 atm; interplanar spacing reported at 77.2 K is 3.339 Å; 3.360 Å at 293.2 K determined by graphical interpolation.
116*	407	Walker, P.L., et al.	1953	X	300-1391	Graphitized Carbon	Similar to the above specimen except expansion measured in Ar atm; interplanar spacing reported at 300.2 K is 3.361 Å; 3.360 Å at 293.2 K determined by graphical extrapolation.
117*	407	Walker, P.L., et al.	1953	X	437-747	Graphitized Carbon	Similar to the above specimen except expansion measured in O_2 atm; interplanar spacing reported at 437.2 K is 3.375 Å; 3.360 Å at 293.2 K determined by graphical extrapolation.
118*	407	Walker, P.L., et al.	1953	X	488-1169	Graphitized Carbon	Similar to the above specimen except expansion measured in CO_2 atm with Fe Kα radiation; interplanar spacing reported at 488.2 K is 3.380 Å; 3.360 Å at 293.2 K determined by graphical extrapolation.
119*	584	Fitzer, E. and Weisenburger, S.	1972	L,O,X	293-1173	Grade AXM-5Q Graphite	High purity specimen; average values of 16 laboratories; ultra-fine grain.
120*	584	Fitzer, E. and Weisenburger, S.	1972	L,O,X	293-1173	Grade AAQ-1 Graphite	Similar to the above specimen.

* Not shown in figure.

SPECIFICATION TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
121*	356	Mason, I.B. and Knibbs, R.H.	1964	L	140-2237		British reactor grade carbon stock; heat treated at 2773 K; expansion measured parallel to extrusion direction; coefficient of thermal expansion also reported.
122*	356	Mason, I.B. and Knibbs, R.H.	1964	L	87-2214		The above specimen; expansion measured perpendicular to extrusion direction.
123*	356	Mason, I.B. and Knibbs, R.H.	1964	L	133-2253		Similar to the above specimen except heat treated to 2973 K; expansion measured parallel to extrusion direction.
124*	356	Mason, I.B. and Knibbs, R.H.	1964	L	85-2235		The above specimen; expansion measured perpendicular to extrusion direction.
125*	357	Hidnert, P.	1934	L	293-623	Sample 1497	Grade 2079 rod 0.394 cm dia; received from Speer Carbon Co.; prepared by hot extrusion process; change in length 0.004% after heating and cooling; expansion measured with increasing temperature.
126*	357	Hidnert, P.	1934	L	293-623	Sample 1498	Similar to the above specimen except grade 2095.
127*	357	Hidnert, P.	1934	L	623-293	Sample 1498	The above specimen; change in length 0.012% after heating and cooling; expansion measured with decreasing temperature.
128*	357	Hidnert, P.	1934	L	293-623	Sample 1498	The above specimen; expansion measured with increasing temperature on second test.
129*	357	Hidnert, P.	1934	L	623-293	Sample 1498	The above specimen; expansion measured with decreasing temperature on second test; change in length 0.011% after heating and cooling.

* Not shown in figure.

DATA TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
300	0.002
477	0.043
588	0.072
700	0.097
810	0.130
922	0.166
1033	0.204
1144	0.244
1255	0.282
1366	0.315

CURVE 2

T	$\Delta L/L_0$
300	0.002*
477	0.050*
588	0.098*
700	0.141
810	0.193
922	0.247
1033	0.298
1144	0.358
1255	0.417
1366	0.469

CURVE 3*

T	$\Delta L/L_0$
300	0.001
477	0.026
588	0.048
700	0.075
810	0.104
922	0.142
1033	0.177
1144	0.216
1255	0.251
1366	0.290

CURVE 4*

T	$\Delta L/L_0$
300	0.002
477	0.046
588	0.084
700	0.124
810	0.171
922	0.222
1033	0.273

CURVE 4 (cont.)*

T	$\Delta L/L_0$
1144	0.328
1255	0.378
1366	0.437

CURVE 5

T	$\Delta L/L_0$
300	0.003*
477	0.079*
588	0.130
700	0.178*
810	0.244
922	0.302
1033	0.364
1144	0.426
1255	0.490
1366	0.551

CURVE 6

T	$\Delta L/L_0$
273	-0.030
293	0.000
1073	1.973
1169	2.448
1273	2.849
1370	3.056
1473	3.561
1573	3.665
1673	4.080
1774	4.243
1874	4.629
1974	4.852
2073	5.134
2173	5.608
2275	5.846
2375	6.098
2473	6.528
2573	6.914
2673	7.166
2773	7.433
2874	7.804
2974	8.190

CURVE 7

T	$\Delta L/L_0$
273	-0.030*
293	0.000*

CURVE 7 (cont.)

T	$\Delta L/L_0$
1073	2.107
1169	2.344
1273	2.715
1370	3.056*
1473	3.561*
1573	3.680*
1673	3.946
1774	4.243*
1874	4.629*
1974	4.955
2073	5.134*
2173	5.490
2275	5.846*
2375	6.098*
2473	6.409
2573	6.795
2673	7.003
2773	7.314
2874	7.671
2974	8.086

CURVE 8

T	$\Delta L/L_0$
294	0.000*
373	0.027
572	0.110
872	0.281*
1272	0.581

CURVE 9

T	$\Delta L/L_0$
294	0.000*
373	0.044*
572	0.170*
872	0.406*
1272	0.792

CURVE 10

T	$\Delta L/L_0$
299	0.001*
477	0.034*
588	0.063*
699	0.097*
810	0.134*
922	0.178*
1033	0.218*

CURVE 10 (cont.)

T	$\Delta L/L_0$
1144	0.262*
1255	0.310
1366	0.352

CURVE 11*

T	$\Delta L/L_0$
299	0.002
477	0.061
588	0.102
699	0.151
810	0.198
922	0.254
1033	0.308
1144	0.360
1255	0.423
1366	0.489

CURVE 12*

T	$\Delta L/L_0$
299	0.002
477	0.050
588	0.090
699	0.132
810	0.182
922	0.222
1033	0.274
1144	0.331
1255	0.390
1366	0.456

CURVE 13*

T	$\Delta L/L_0$
299	0.003
477	0.070
588	0.114
699	0.153
810	0.188
922	0.225
1033	0.266
1144	0.314
1255	0.365
1366	0.413

CURVE 14*

T	$\Delta L/L_0$
299	0.002

CURVE 14 (cont.)*

T	$\Delta L/L_0$
477	0.046
588	0.073
699	0.102
810	0.135
922	0.169
1033	0.202
1144	0.241
1255	0.279
1366	0.321

CURVE 15*

T	$\Delta L/L_0$
299	0.001
477	0.026
588	0.050
699	0.080
810	0.113
922	0.149
1033	0.186
1144	0.225
1255	0.267
1366	0.303

CURVE 16*

T	$\Delta L/L_0$
303	0.002
373	0.018

CURVE 17*

T	$\Delta L/L_0$
303	0.002
373	0.019

CURVE 18

T	$\Delta L/L_0$
295	0.003*
371	0.034*
472	0.086*
573	0.149*
675	0.225
773	0.307*
876	0.387
976	0.473
1072	0.552
1173	0.626
1273	0.676

CURVE 19*

T	$\Delta L/L_0$
295	0.001
373	0.033
473	0.077
573	0.135
673	0.203
773	0.274
873	0.352
973	0.429
1073	0.502
1173	0.571
1277	0.618

CURVE 20*

T	$\Delta L/L_0$
293	0.000
373	0.001

CURVE 21*

T	$\Delta L/L_0$
293	0.000
373	0.018

CURVE 22*

T	$\Delta L/L_0$
293	0.000
373	0.030

CURVE 23

T	$\Delta L/L_0$
295	0.001*
373	0.030*
473	0.072*
573	0.121*
673	0.176
773	0.239
873	0.304
973	0.370
1073	0.442
1173	0.513
1273	0.595*

CURVE 24

T	$\Delta L/L_0$
295	0.000*
373	0.017*
473	0.045*

* Not shown in figure.

DATA TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES (continued)

T	$\Delta L/L_0$
CURVE 24 (cont.)	
573	0.073
673	0.114
773	0.160
873	0.206
973	0.257
1073	0.309
1173	0.360
1273	0.417
CURVE 25	
6	-0.295
78	-0.236
193	-0.059
293	0.000*
298	0.265
1007	1.768
1045	2.062
1104	2.121
1167	2.209
1221	2.151
1262	2.328
1314	2.769
1359	2.887
1393	3.035
1439	2.858
1476	3.094
1533	3.094
1588	3.182
1650	3.742
1691	3.712
1748	4.184
1802	4.036
1856	4.426
1897	4.862
1949	4.567
2000	4.832
2061	4.891
2101	5.186
2146	5.303
2181	5.068
2260	5.480
2328	5.569
2400	5.657
2448	6.099
2498	6.128
2552	6.541
2624	6.836
2679	7.071

T	$\Delta L/L_0$
CURVE 26	
6	0.0814
78	0.0407
193	0.0814
298	0.0000*
CURVE 27	
313	0.008*
352	0.024
393	0.033*
431	0.044
473	0.058*
511	0.073*
549	0.088
588	0.096*
629	0.111
673	0.125*
711	0.141*
750	0.154
789	0.168*
830	0.182
873	0.193*
909	0.205*
952	0.223
991	0.239*
1028	0.256*
1073	0.268*
1107	0.284
1149	0.300*
1189	0.315*
1230	0.330
1273	0.345*
1311	0.359
1351	0.375*
1392	0.385*
1430	0.393
1473	0.408*
1513	0.427
1550	0.442*
1592	0.462
1608	0.473*
CURVE 28	
315	0.006
336	0.012*
353	0.019*
371	0.027*
392	0.031

T	$\Delta L/L_0$
CURVE 28 (cont.)	
415	0.035*
433	0.040*
452	0.045
473	0.050*
512	0.062
553	0.074*
591	0.086*
630	0.103*
669	0.114*
710	0.130
751	0.140*
790	0.151
831	0.167*
873	0.179*
907	0.195
946	0.213*
992	0.232
1028	0.246*
1068	0.263*
1108	0.278*
1146	0.290*
1190	0.305
1228	0.320*
1267	0.335*
1307	0.348*
1350	0.360
1389	0.368*
1428	0.382*
1473	0.397
1514	0.416*
1551	0.436
1591	0.455*
1612	0.462
CURVE 29	
292	-0.001*
303	0.005*
315	0.010*
332	0.016
352	0.025*
373	0.036*
394	0.042*
411	0.049
435	0.057*
473	0.075*
493	0.082
514	0.092*
555	0.113*

T	$\Delta L/L_0$
CURVE 29 (cont.)	
593	0.129*
633	0.154*
673	0.174*
713	0.193*
753	0.211*
793	0.234*
831	0.254
873	0.276*
912	0.299
953	0.323*
992	0.347
1029	0.371*
1073	0.396*
1111	0.420
1148	0.442*
1189	0.464*
1232	0.485
1273	0.510*
1312	0.532*
1352	0.550
1391	0.570*
1434	0.592
1473	0.611*
1513	0.633
1554	0.663*
1594	0.691
1613	0.704*
CURVE 30	
289	-0.002*
308	0.006*
329	0.015*
349	0.026*
367	0.036*
390	0.046*
409	0.052*
428	0.060*
447	0.071*
473	0.079*
489	0.087*
510	0.094*
529	0.101
547	0.108*
570	0.122*
592	0.134*
610	0.141
629	0.147*
646	0.155

T	$\Delta L/L_0$
CURVE 30 (cont.)	
673	0.165*
686	0.176*
710	0.185*
729	0.194
750	0.204*
771	0.217*
791	0.224
811	0.236*
831	0.242*
873	0.263*
911	0.290*
951	0.317
988	0.339*
1029	0.363*
1073	0.386*
1107	0.406*
1146	0.427*
1188	0.448
1227	0.469*
1273	0.492
1307	0.513
1348	0.532*
1388	0.547
1430	0.569*
1473	0.587
1511	0.610*
1547	0.627
1593	0.655*
1625	0.679
CURVE 31*	
299	0.002
477	0.065
588	0.114
699	0.166
810	0.224
922	0.275
1033	0.333
1144	0.389
1255	0.443
1366	0.487
CURVE 32*	
299	0.002
477	0.056
588	0.092
699	0.135

T	$\Delta L/L_0$
CURVE 32 (cont.)*	
810	0.175
922	0.222
1033	0.273
1144	0.329
1255	0.376
1366	0.429
CURVE 33*	
299	0.002
477	0.058
588	0.095
699	0.138
810	0.185
922	0.234
1033	0.284
1144	0.342
1255	0.398
1366	0.452
CURVE 34	
115	-0.016
139	-0.015*
165	-0.014*
191	-0.013*
213	-0.011
240	-0.008
263	-0.005*
546	0.046*
664	0.073*
911	0.136*
1140	0.201*
1674	0.385
1930	0.489
2126	0.573
2327	0.663
CURVE 35	
89	-0.059
117	-0.055*
137	-0.052
156	-0.048*
186	-0.039*
212	-0.030*
233	-0.023*
258	-0.014
458	0.065*

* Not shown in figure.

DATA TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES (continued)

T	$\Delta L/L_0$
CURVE 35 (cont.)	
681	0.163*
886	0.260
1071	0.352*
1608	0.648
1859	0.793
2089	0.931
2295	1.074
CURVE 36	
293	0.000*
1099	0.184
1238	0.254
1355	0.293
1444	0.369
1549	0.412*
1691	0.488
1749	0.642
1827	0.641
1941	0.682
2049	0.715
2202	0.835
CURVE 37	
293	0.000*
1199	0.299*
1305	0.492*
1416	0.568
1558	0.647*
1649	0.728
1755	0.800
1877	0.881
2027	0.962
2110	1.034
2188	1.136
2294	1.264
CURVE 38	
293	0.000*
1022	0.186*
1133	0.296
1305	0.492*
1472	0.618*
1516	0.720
1649	0.957
1760	1.107

T	$\Delta L/L_0$
CURVE 39	
293	0.000*
1155	0.492*
1285	0.565
1416	0.653
1522	0.765*
1622	0.847
1822	0.919
2027	1.038
2185	1.192*
2324	1.333
CURVE 40*	
295	0.001
373	0.039
473	0.091
573	0.152
673	0.221
773	0.296
873	0.369
973	0.478
1073	0.523
1173	0.605
1273	0.693
CURVE 41*	
295	0.001
373	0.039
473	0.083
573	0.142
673	0.206
773	0.275
873	0.350
973	0.419
1073	0.491
1173	0.567
1273	0.651
CURVE 42	
295	0.000*
373	0.011*
473	0.035*
573	0.061*
673	0.092*
773	0.128*
873	0.167*

T	$\Delta L/L_0$
CURVE 42 (cont.)	
973	0.207
1073	0.247
1173	0.291
1273	0.340
CURVE 43*	
295	0.000
373	0.017
473	0.049
573	0.091
673	0.132
773	0.184
873	0.237
973	0.290
1073	0.341
1173	0.399
1273	0.460
CURVE 44*	
299	0.002
477	0.052
588	0.092
699	0.138
810	0.181
922	0.234
1033	0.284
1144	0.342
1255	0.393
1366	0.448
CURVE 45*	
299	0.003
477	0.082
588	0.136
699	0.195
810	0.255
922	0.318
1033	0.388
1144	0.453
1255	0.523
1366	0.591
CURVE 46*	
299	0.003

T	$\Delta L/L_0$
CURVE 46 (cont.)*	
477	0.079
588	0.137
699	0.195
810	0.256
922	0.373
1033	0.389
1144	0.458
1255	0.533
1366	0.599
CURVE 47	
293	0.000*
359	0.036*
535	0.131*
871	0.312*
984	0.376*
1144	0.476*
1361	0.623*
1683	0.852
1922	1.019
2195	1.205
2477	1.389
CURVE 48	
293	0.000*
541	0.129*
811	0.270*
1366	0.613*
1620	0.795
1922	1.016*
2109	1.155
2339	1.326
2499	1.445
CURVE 49*	
295	0.000
373	0.009
473	0.035
573	0.059
673	0.084
773	0.117
873	0.152
973	0.192
1073	0.231
1173	0.268
1273	0.312

T	$\Delta L/L_0$
CURVE 50*	
295	0.000
373	0.019
473	0.047
573	0.084
673	0.128
773	0.174
873	0.223
973	0.274
1073	0.325
1173	0.379
1273	0.438
CURVE 51	
288	-0.008*
1001	2.009
1461	3.413
CURVE 52*	
78	-1.632
293	0.000
297	0.030
CURVE 53*	
295	0.000
373	0.016
473	0.042
573	0.070
673	0.106
773	0.150
873	0.197
973	0.247
1073	0.292
1173	0.340
1273	0.396
CURVE 54*	
295	0.000
373	0.007
473	0.031
573	0.061
673	0.091
773	0.126
873	0.166
973	0.206

T	$\Delta L/L_0$
CURVE 54 (cont.)*	
1073	0.253
1173	0.296
1273	0.348
CURVE 55*	
293	0.000
1366	0.450
1644	0.579
1922	0.739
2199	0.940
2477	1.148
2755	1.361
CURVE 56*	
293	0.000
1366	0.433
1644	0.591
1922	0.771
2199	0.978
2477	1.203
2755	1.494
CURVE 57*	
293	0.000
1366	0.475
1644	0.610
1922	0.780
2199	0.982
2477	1.187
2755	1.396
CURVE 58*	
293	0.000
1366	0.452
1644	0.618
1922	0.803
2199	1.009
2477	1.227
2755	1.498

* Not shown in figure.

DATA TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES (continued)

T	$\Delta L/L_0$
CURVE 59*	
293	0.000
373	0.025
473	0.061
573	0.099
673	0.138
773	0.177
873	0.222
973	0.270
1073	0.319
CURVE 60*	
293	0.000
373	0.025
473	0.058
573	0.097
673	0.140
773	0.185
873	0.232
973	0.279
1073	0.327
CURVE 61*	
293	0.000
373	0.035
473	0.079
573	0.124
673	0.173
773	0.224
873	0.274
973	0.323
1073	0.375
CURVE 62*	
293	0.000
373	0.041
473	0.095
573	0.152
673	0.210
773	0.268
873	0.329
973	0.389
1073	0.451

T	$\Delta L/L_0$
CURVE 63	
298	0.0025*
373	0.0413*
473	0.0939*
673	0.2026*
873	0.3156*
1073	0.4330*
1273	0.5548*
1473	0.6809
1673	0.8115
1873	0.9464
2073	1.0857
2273	1.2294
2473	1.3775*
2673	1.5299
2773	1.6078
CURVE 64	
298	0.0027*
373	0.0446*
473	0.1015*
673	0.2193*
873	0.3420*
1073	0.4698*
1273	0.6027*
1473	0.7406
1673	0.8835
1873	1.0315
2073	1.1845
2273	1.3425
2473	1.5056
2673	1.6738
2743	1.7338
CURVE 65*	
293	0.000
523	0.134
773	0.297
1023	0.451
1273	0.615
1523	0.776
1773	0.947
2023	1.131
2273	1.325
2523	1.529
2773	1.769
3023	2.046
3156	2.205

T	$\Delta L/L_0$
CURVE 66*	
293	0.000
523	0.140
773	0.302
1023	0.463
1273	0.634
1523	0.804
1773	0.985
2023	1.174
2273	1.365
2523	1.578
2773	1.819
3023	2.097
3109	2.193
CURVE 67*	
293	0.000
523	0.152
773	0.324
1023	0.488
1273	0.663
1523	0.846
1773	1.033
2023	1.222
2273	1.428
2573	1.649
2773	1.901
3023	2.210
3083	2.288
CURVE 68*	
295	0.000
373	0.017
472	0.056
573	0.095
673	0.135
773	0.175
873	0.208
973	0.245
1053	0.273
1073	0.282
CURVE 69*	
295	0.001
373	0.044
472	0.128

T	$\Delta L/L_0$
CURVE 69 (cont.)*	
573	0.209
673	0.284
773	0.360
873	0.437
973	0.515
1057	0.573
1073	0.578
CURVE 70*	
295	0.001
373	0.052
473	0.135
573	0.218
673	0.295
773	0.372
873	0.452
973	0.533
1057	0.596
1073	0.601
CURVE 71*	
295	0.000
373	0.018
473	0.056
573	0.096
673	0.132
773	0.170
873	0.205
973	0.241
1054	0.269
1073	0.276
CURVE 72*	
295	0.001
373	0.046
473	0.116
573	0.200
673	0.293
773	0.384
873	0.484
973	0.584
CURVE 73*	
295	0.001

T	$\Delta L/L_0$
CURVE 73 (cont.)*	
373	0.030
473	0.057
573	0.089
673	0.128
773	0.167
873	0.214
CURVE 74*	
295	0.001
373	0.020
473	0.046
573	0.077
673	0.118
773	0.153
873	0.196
CURVE 75*	
293	0.000
1034	1.877
1053	1.787
1067	1.906
1144	2.383
1206	2.651
1237	2.502
1266	2.293
1273	2.681
1297	2.651
1351	2.651
1380	2.681
1400	2.770
1428	2.859
1485	2.800
1518	3.247
1533	3.187
1621	3.634
1650	3.694
1709	3.604
1755	4.170
1773	4.289
1791	4.229
1842	4.558
1897	4.528
1941	4.796
1990	4.945
2018	4.826
2046	4.975

T	$\Delta L/L_0$
CURVE 75 (cont.)*	
2098	5.094
2117	5.273
2175	5.332
2227	5.659
2298	5.659
2304	6.017
2332	5.868
2343	5.868
2367	5.868
2367	6.047
2391	6.107
2432	6.017
2471	6.493
2497	6.494
2600	6.881
CURVE 76*,†	
1273	0.000
1469	0.091
1673	0.178
1873	0.321
2076	0.472
2273	0.605
2475	0.805
2670	1.003
CURVE 77*,†	
2670	0.000
2478	-0.295
2277	-0.493
2079	-0.641
1872	-0.776
1674	-0.890
1472	-0.971
1273	-1.051
CURVE 78*,†	
1273	0.000
1480	0.101
1674	0.204
1870	0.307
2075	0.425
2276	0.582
2470	0.764
2671	0.963

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES (continued)

T	$\Delta L/L_0$
CURVE 79*,†	
2671	0.000
2071	-0.575
1873	-0.711
1669	-0.833
1472	-0.932
1273	-1.011
CURVE 80*,†	
1273	0.000
1469	0.092
1676	0.217
1874	0.311
2075	0.449
2278	0.608
2474	0.779
2672	0.967
CURVE 81*,†	
2672	0.000
2476	-0.213
2283	-0.406
2072	-0.565
1873	-0.688
1672	-0.790
1472	-0.908
1273	-1.008
CURVE 82*,†	
1273	0.000
1473	0.057
1671	0.119
1869	0.175
2145	0.265
2269	0.309
2478	0.405
2674	0.509
CURVE 83*,†	
2674	0.000
2478	-0.122
2269	-0.223
2072	-0.273
1873	-0.357
1671	-0.415

T	$\Delta L/L_0$
CURVE 83 (cont.)*,†	
1473	-0.478
1273	-0.518
CURVE 84*,†	
1275	0.000
1473	0.072
1671	0.134
1873	0.199
2076	0.254
2282	0.314
2479	0.405
2674	0.466
CURVE 85*,†	
2674	0.000
2479	-0.061
2282	-0.152
2068	-0.234
1869	-0.292
1674	-0.349
1466	-0.412
1275	-0.466
CURVE 86*	
300	0.003
819	0.212
1263	0.435
1633	0.624
CURVE 87*	
293	0.000
373	0.010
CURVE 88	
293	0.000*
773	0.073
1273	0.196
1773	0.353
2273	0.536
2673	0.695

T	$\Delta L/L_0$
CURVE 89*	
293	0.000
373	0.054
CURVE 90	
293	0.000*
773	0.412*
1273	0.897
1773	1.416
2273	2.062
2673	2.725
CURVE 91*	
293	0.000
373	0.006
CURVE 92*	
293	0.000
773	0.081
1273	0.213
1773	0.370
2273	0.572
2673	0.756
CURVE 93*	
293	0.000
373	0.054
CURVE 94	
293	0.000*
773	0.329*
1273	0.728*
1773	1.175
2273	1.762
2673	2.423
CURVE 95*	
293	0.000
373	0.006
CURVE 96*	
293	0.000
373	0.054

T	$\Delta L/L_0$
CURVE 97*	
293	0.000
373	0.005
CURVE 98	
293	0.000*
773	0.064*
1273	0.197*
1773	0.374*
2273	0.577*
2673	0.762
CURVE 99*	
293	0.000
373	0.066
CURVE 100	
293	0.000*
773	0.412*
1273	0.890*
1773	1.437*
2273	2.066*
2673	2.822
CURVE 101*	
293	0.000
373	0.005
CURVE 102*	
293	0.000
373	0.064
CURVE 103*	
78	-2.047
293	0.000
297	0.038
CURVE 104*	
288	-0.0149
423	0.3465
573	0.7791
723	1.1934

T	$\Delta L/L_0$
CURVE 104 (cont.)*	
873	1.6324
973	1.9222
1073	2.2254
CURVE 105*	
288	0.0008
423	-0.0199
573	-0.0220
723	-0.0191
873	-0.0204
973	-0.0069
1073	-0.0045
CURVE 106*	
288	0.0008
423	-0.0208
573	-0.0212
723	-0.0179
873	-0.0167
973	-0.0053
1073	0.0016
CURVE 107*	
298	0.0004
773	0.039
CURVE 108*	
298	0.004
773	0.367
CURVE 109	
298	0.001*
918	0.074
CURVE 110	
298	0.005*
918	0.582
CURVE 111*	
298	0.001
918	0.072

T	$\Delta L/L_0$
CURVE 112*	
298	0.004
918	0.502
CURVE 113*	
298	0.0004
918	0.057
CURVE 114*	
298	0.004
918	0.511
CURVE 115*	
77	-0.625
301	0.029
489	0.565
662	1.071
777	1.428
878	1.637
975	1.934
1064	2.173
1169	2.470
1289	2.857
CURVE 116*	
300	0.029
490	0.536
798	1.399
885	1.667
965	1.905
1056	2.262
1156	2.411
1267	2.679
1391	3.125
CURVE 117*	
437	0.446
587	0.863
747	1.250
CURVE 118*	
488	0.595
689	1.131

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 27. THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES (continued)

T	$\Delta L/L_0$
CURVE 118 (cont.)*	
869	1.607
1001	2.024
1169	2.470
CURVE 119*	
293	0.000
573	0.198
773	0.358
973	0.520
1173	0.634
CURVE 120*	
293	0.000
573	0.057
773	0.115
973	0.176
1173	0.246
CURVE 121*,‡	
140	-0.017
165	-0.017
184	-0.016
213	-0.013
232	-0.010
262	-0.005
427	0.023
651	0.070
880	0.127
1114	0.197
1581	0.361
1822	0.459
2044	0.552
2237	0.634
CURVE 122*,‡	
87	-0.049
113	-0.048
140	-0.045
162	-0.041
186	-0.036
212	-0.028
239	-0.020
264	-0.011
416	0.046
646	0.135
CURVE 122 (cont.)*,‡	
865	0.227
1100	0.336
1563	0.595
1802	0.741
2017	0.882
2214	1.021
CURVE 123*,‡	
133	-0.014
165	-0.014
186	-0.013
213	-0.010
236	-0.008
263	-0.004*
429	0.018
641	0.054
862	0.105
1110	0.176
1577	0.322
1828	0.414
2053	0.499
2253	0.575
CURVE 124*,‡	
85	-0.044
110	-0.044
133	-0.042
166	-0.038
184	-0.034
211	-0.027
235	-0.019
259	-0.011
412	0.040
601	0.107
876	0.216
1074	0.305
1578	0.569
1827	0.724
2038	0.860
2235	0.991
CURVE 125*	
293	0.000
333	0.0056
373	0.012
473	0.025
573	0.048
623	0.059
CURVE 126*	
293	0.000
333	0.016
373	0.033
473	0.077
573	0.13
623	0.16
CURVE 127*	
623	0.14
473	0.076
373	0.031
293	0.000
CURVE 128*	
293	0.000
333	0.016
373	0.032
473	0.077
573	0.13
623	0.16
CURVE 129*	
623	0.15
473	0.076
373	0.030
293	0.000

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 27. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS GRAPHITES

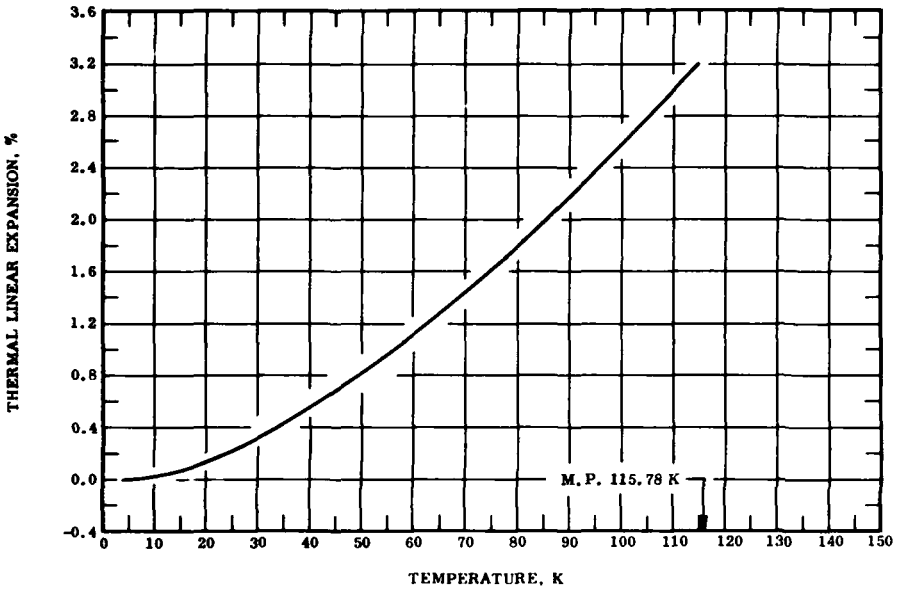
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 25*	
800	26.3
900	26.7
1000	27.2
1100	27.6
1200	28.1
1300	28.2
1400	28.5
1500	28.9
1600	29.4
1700	29.9
1800	30.5
1900	31.1
2000	31.3
2100	32.5
2200	33.0
2300	33.0
2400	33.2
CURVE 34	
115	0.16
139	0.24
165	0.43
191	0.65
213	0.85
240	1.15
263	1.42
546	2.20
664	2.38
911	2.73
1140	2.96
1674	3.93
1930	4.21
2126	4.31
2327	4.67
CURVE 35	
89	1.00
117	1.59
137	1.99
156	2.39
186	3.37
212	3.40
233	3.59
258	3.56
458	4.32
681	4.49
886	4.91
1071	5.12
1608	5.89
1859	5.65
2089	6.39
2295	7.48
CURVE 47*	
293	5.40
359	5.40
535	5.40
871	5.40
984	5.98
1144	6.41
1361	7.16
1683	7.06
1922	6.98
2195	6.64
2477	6.39
CURVE 48*	
293	5.15
541	5.22
811	5.29
1366	7.06
1620	7.22
1922	7.42
2109	7.45
2339	7.43
2499	7.49
CURVE 121*,‡	
140	0.07
165	0.40
184	0.84
213	1.19
232	1.53
262	1.62
427	1.88
651	2.28
880	2.73
1114	3.23
1581	3.77
1822	4.36
2044	4.02
2237	4.50
CURVE 122*,‡	
87	0.44
113	0.79
140	1.37
162	1.99
186	2.56
212	3.18
239	3.26
264	3.69
416	3.79
646	3.96
865	4.42
1100	4.90
1563	6.26
1802	5.99
2017	7.14
2214	6.90
CURVE 123*,‡	
133	0.00
165	0.39
186	0.71
213	1.03
236	1.33
263	1.33
429	1.29
641	2.11
862	2.56
1110	3.11
1577	3.16
1828	4.15
2053	3.45
2253	4.07
CURVE 124*,‡	
85	0.05
110	0.25
133	0.89
166	1.77
184	2.37
211	2.99
235	3.38
259	3.30
412	3.39
601	3.77
876	4.15
1074	4.82
1578	5.67
2038	6.21
2235	7.07

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 28R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF KRYPTON Kr



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$ [§]	α
4	0.00	5
10	0.01	60
15	0.05	120
20	0.18	156
25	0.26	200
30	0.35	222
35	0.46	240
40	0.58	255
45	0.70	267
50	0.84	276
60	1.14	310
70	1.46	345
80	1.83	370
90	2.20	385
100	2.60	415
110	3.03	420
115	3.23	425

[§] Reference temperature 4.0 K at which $\Delta L/L_0 = 0$.

REMARKS

The recommended values are based on the data for pure samples and are considered accurate to within ±3%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.022 + 4.286 \times 10^{-2} T + 2.983 \times 10^{-4} T^2 - 7.766 \times 10^{-7} T^3$$

The tabulated values for the coefficient of thermal expansion are primarily derived from the experimental data (curves 9 and 10) and are considered accurate to about ± 5%.

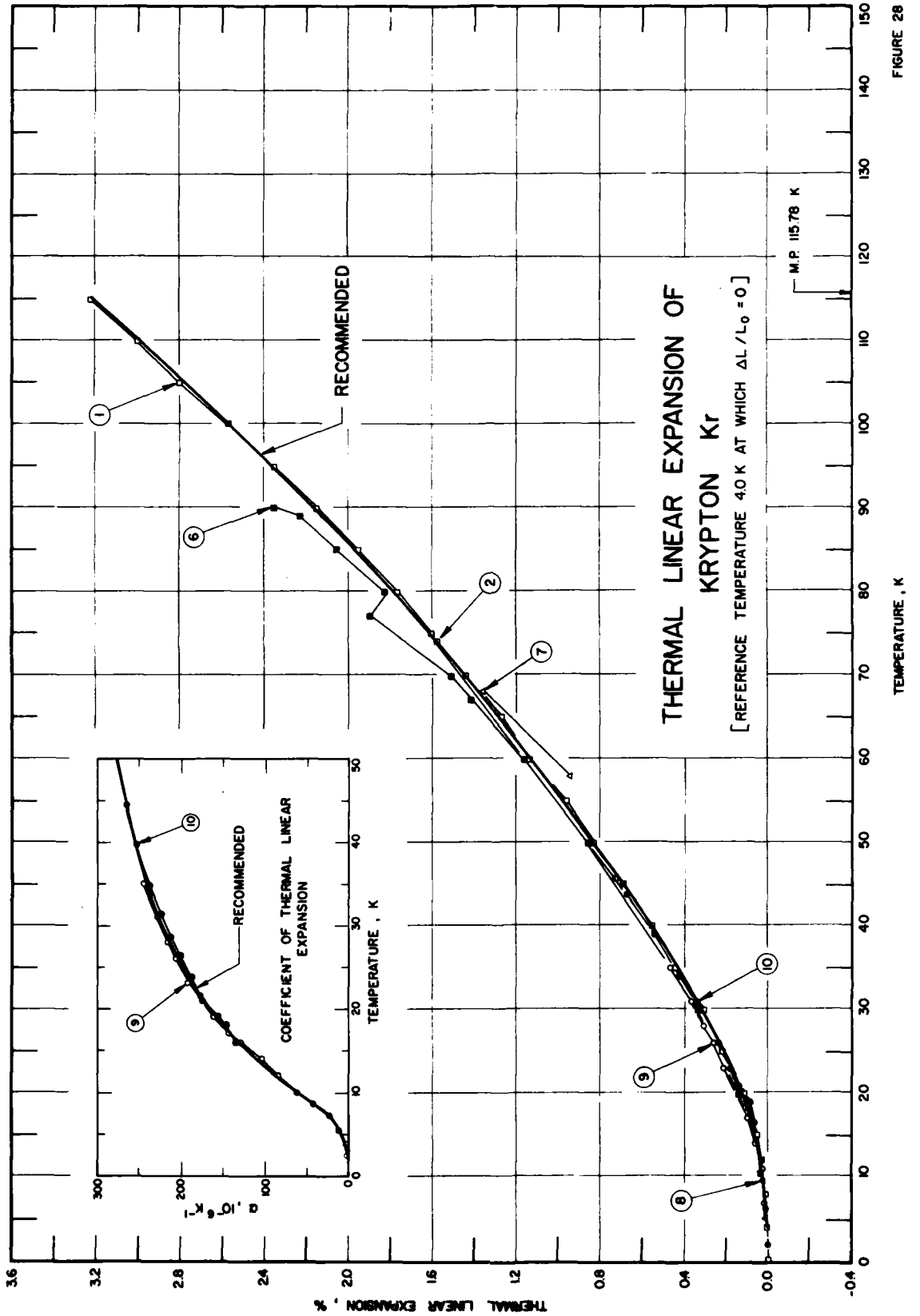

THERMAL LINEAR EXPANSION OF
KRYPTON Kr
[REFERENCE TEMPERATURE 4.0 K AT WHICH ΔL/L0 = 0]
M.P. 115.78 K
RECOMMENDED
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
α , 10⁻⁶ K⁻¹
TEMPERATURE , K

FIGURE 28

SPECIFICATION TABLE 28. THERMAL LINEAR EXPANSION OF KRYPTON Kr

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	488	Losee, D. L. and Simmons, R. O.	1968	X	4-115		Research grade specimen from Matheson Co.; 0.0025 N principal impurity; specimen solidified from liquid very slowly with uniform temperature gradient; expansion measured in low-pressure helium atm; data from curve smoothed by author; reported error < 0.2% for temperature higher than 20 K; lattice parameter reported at 0 K is 5.64587 Å; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
2	489	Urvas, A. O., Losee, D. L., and Simmons, R. O.	1967	X	10.3-74.0		99.995 pure specimen from Matheson Co.; crystal grown by directional solidification techniques; expansion measured with increasing temperature under 1.4 bar pressure helium atm; Cu$K\alpha_1$ diffraction used for (640) planes; lattice parameter reported at 10.3 K is 5.64698 Å; 5.64480 Å at 4.0 K used for data conversion; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
3*	489	Urvas, A. O., et al.	1967	X	10.3-74.0		The above specimen; expansion measured at 1.8 bar of He atm; lattice parameter reported at 10.3 K is 5.64689 Å; 5.64480 Å at 4.0 K used for data conversion; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
4*	489	Urvas, A. O., et al.	1967	X	10.3-74.0		The above specimen; expansion measured at 20.0 bar of He atm; lattice parameter reported at 10.3 K is 5.64599 Å; 5.6448 Å at 4.0 K used for data conversion; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
5*	489	Urvas, A. O., et al.	1967	X	10.3-74.0		The above specimen; expansion measured at 18.6 bar of He atm; lattice parameter reported at 10.3 K is 5.64592 Å; 5.64480 Å at 4.0 K used for data conversion; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
6	490	Figgins, B. F. and Smith, B. L.	1960	X	20-90		< 0.5 Xe and < 0.001 all other impurities; obtained from British Oxygen Co.; lattice parameter reported at 20 K is 5.653 Å; 5.645 Å at 4.0 K used for data conversion; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
7	491	Cheesman, G. H. and Loane, C. M.	1957	X	58,68		99-100 commercial purity with principal impurity Xe; measurement of lattice constant referred to Cu at 293 K; lattice constant reported at 58 K is 5.710 kX (or 5.699 Å); 5.645 Å at 4.0 K used for data conversion; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
8	492	Tilford, C. R. and Swenson, C. A.	1972	E	0-45		Specimen 0.375 in diameter, 30 mm long; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
9	492	Tilford, C. R. and Swenson, C. A.	1972	E	1-35	Set I	Similar to the above specimen; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
10	492	Tilford, C. R. and Swenson, C. A.	1972	E	1-45	Set II	Similar to the above specimen; capacitance-cell gap made smaller for second set by heating cell to a temperature greater than initial assembly temperature; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

DATA TABLE 28. THERMAL LINEAR EXPANSION OF KRYPTON Kr

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1§	
0	-0.0004
4	0.0000
6	0.0018*
8	0.0070
10	0.0170*
15	0.0583
20	0.128
25	0.217
30	0.320
35	0.434
40	0.557
45	0.687
50	0.823
55	0.965
60	1.144
65	1.270
70	1.433
75	1.604
80	1.782
85	1.968
90	2.163
95	2.366
100	2.578
105	2.805
110	3.051
115	3.317
CURVE 2§	
10.3	0.0386
45.9	0.7277
74.0	1.5877
CURVE 3*,§	
10.3	0.0370
45.9	0.7258
74.0	1.5846
CURVE 4*,§	
10.3	0.0211
45.9	0.7086
74.0	1.5621

T	$\Delta L/L_0$
CURVE 5*,§	
10.3	0.0198
45.9	0.7047
74.0	1.5579
CURVE 6§	
20	0.142
30	0.337
40	0.567*
50	0.832
60	1.169
67	1.417
70	1.523
77	1.896
80	1.825
85	2.037
89	2.214
90	2.338
CURVE 7§	
58	0.957
68	1.374
CURVE 8§	
1	-0.000360*
1.5	-0.000355*
2	-0.000341*
2.5	-0.000310*
3	-0.000253*
3.5	-0.000156*
4	0.000000*
4.5	0.000237*
5	0.000583
5.5	0.00106*
6	0.00171*
6.5	0.00254*
7	0.00358*
7.5	0.00487*
8	0.00641*
8.5	0.00823*
9	0.0103*
9.5	0.0127
10	0.0154*
10.5	0.0186*

T	$\Delta L/L_0$
CURVE 8 (cont.)§	
11	0.0205*
12	0.0293
13	0.0380*
14	0.0479*
15	0.0588*
16	0.0708*
18	0.0979
20	0.128*
25	0.217*
30	0.320*
35	0.434*
40	0.557*
45	0.687*
CURVE 9‡,§	
1.635	-0.00037*
1.846	-0.00036*
2.041	-0.00035*
2.252	-0.00034*
2.484	-0.00033*
2.730	-0.00030*
2.999	-0.00027*
3.287	-0.00021*
3.587	-0.00014*
3.930	-0.00003*
4.328	0.00014*
4.786	0.00043*
5.322	0.00089*
5.881	0.00158*
6.471	0.00256*
7.120	0.00399*
7.830	0.00603
8.782	0.00967
9.611	0.01371
10.332	0.0179*
11.163	0.0236
12.101	0.0310*
13.323	0.0423*
14.658	0.0566
16.119	0.0746*
17.698	0.0964
19.441	0.123*
21.572	0.159*
23.909	0.202
26.300	0.250

T	$\Delta L/L_0$
CURVE 9 (cont.)‡,§	
28.854	0.304
31.340	0.360
35.091	0.449
CURVE 10‡,§	
1.484	-0.00011*
1.645	-0.00011*
1.820	-0.00011*
2.009	-0.00010
2.219	-0.00009*
2.449	-0.00007*
6.477	0.00012
16.820	0.0698
18.071	0.0874
19.457	0.108*
21.591	0.144
23.931	0.186
26.324	0.233
28.880	0.286*
31.336	0.339
34.985	0.424
39.851	0.543
44.853	0.673

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.
§ This curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 28. COEFFICIENT OF THERMAL LINEAR EXPANSION OF KRYPTON Kr

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

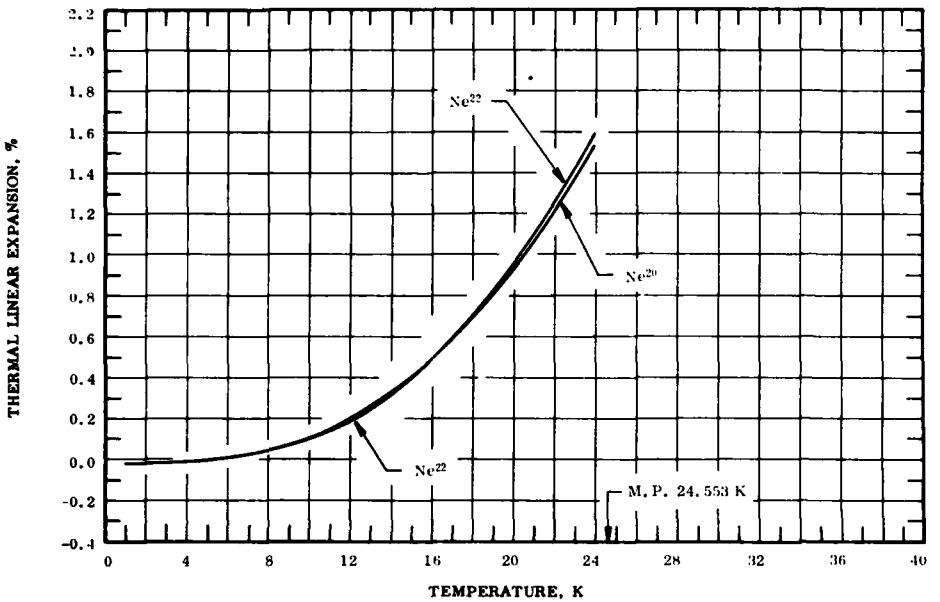
T	α
CURVE 9‡	
1.635	0.2381*
1.846	0.334*
2.041	0.466*
2.252	0.611*
2.484	0.847*
2.730	1.136
2.999	1.539*
3.287	2.064*
3.587	2.753*
3.930	3.747
4.328	5.14*
4.786	7.25*
5.322	10.26
5.881	14.13*
6.471	18.97*
7.120	25.09
7.830	32.60*
8.782	43.72
9.611	53.8*
10.332	62.9
11.163	73.5*
12.101	85.1
13.323	99.9*
14.658	114.9
16.119	130.7
17.698	145.7
19.441	160.9
21.572	177.0
23.909	192.2
26.300	206.1
28.854	218.8
31.340	229.8
35.091	243.6
CURVE 10‡	
1.484	0.169*
1.645	0.227*
1.820	0.311*
2.009	0.422*
2.219	0.571*
2.449	0.784*
6.477	0.189*
16.820	134.6
18.071	146.2
19.457	157.7

T	α
CURVE 10 (cont.)‡	
21.591	173.3
23.931	188.3
26.324	201.7
28.880	214.2
31.336	224.3
34.985	237.1
39.851	253.4
44.853	267.6

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 29R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF NEON Ne



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Ne^{20}		Ne^{22}	
T	$\Delta L/L_0$ [1]	α	$\Delta L/L_0$ [1]	α
1	-0.0019			
2	-0.0018	3		
3	-0.0013	9	-0.0010	
4	0.0000	19	0.0000	16
5	0.0044	69	0.0035	45
6	0.014	123	0.0091	102
8	0.050	243	0.042	230
10	0.112	379	0.103	377
12	0.203	532	0.194	542
14	0.326	701	0.320	724
16	0.484	886	0.485	929
18	0.682	1087	0.692	1143
20	0.920	1304	0.944	1380
22	1.205	1538	1.245	1634
24	1.537	1788	1.598	1907

[1] This curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.

REMARKS

The recommended values for N^{20} are based on the data for pure samples and the values for isotype N^{22} are based on the experimental data reported in curves 2, 7 and 10. These values are considered accurate to within ±5% and are represented approximately by the following equations:

$\underline{Ne^{20}}$: $\Delta L/L_0 = 0.026 - 1.400 \times 10^{-2}\, T + 1.584 \times 10^{-3}\, T^2 + 6.757 \times 10^{-5}\, T^3$ (4-24 K)

$\underline{Ne^{22}}$: $\Delta L/L_0 = 0.039 - 1.756 \times 10^{-2}\, T + 1.640 \times 10^{-3}\, T^2 + 7.497 \times 10^{-5}\, T^3$ (4-24 K)

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

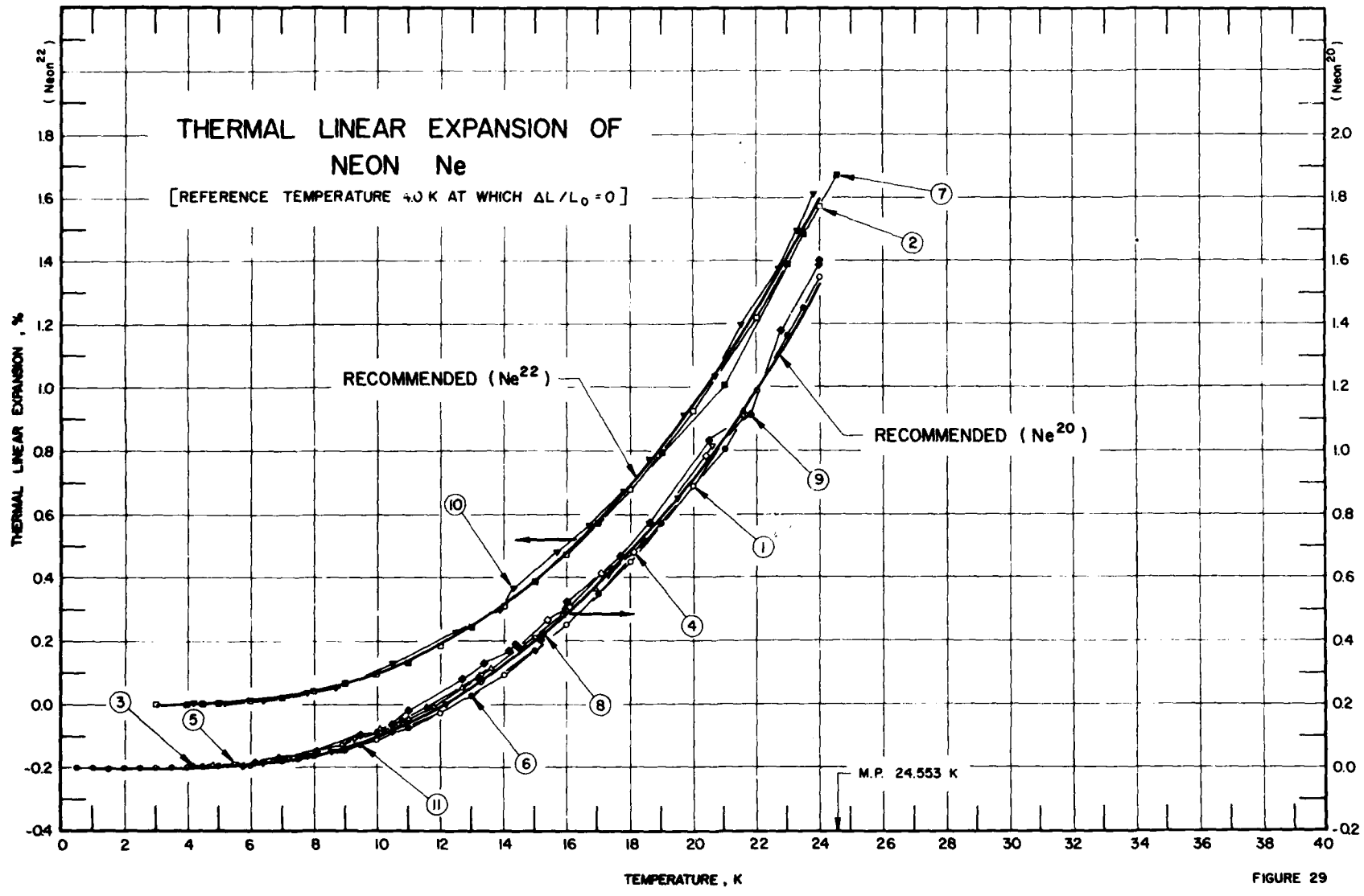

THERMAL LINEAR EXPANSION OF
NEON Ne
[REFERENCE TEMPERATURE 4.0 K AT WHICH ΔL/L0 = 0]
RECOMMENDED (Ne22)
RECOMMENDED (Ne20)
M.P. 24.553 K
THERMAL LINEAR EXPANSION, %
(Neon22)
(Neon20)
TEMPERATURE, K
1
2
3
4
5
6
7
8
9
10
11

FIGURE 29

SPECIFICATION TABLE 29. THERMAL LINEAR EXPANSION OF NEON Ne

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	495	Batchelder, D.N., Losee, D.L., and Simmons, R.O.	1968	X	3-24	Ne^{20}	99.0 Ne^{20}, 0.10 Ne^{21}, 0.90 Ne^{22}; from Mound Laboratory of Monsanto Chemical Co.; crystal grown by progressive solidification from the melt; expansion along a-axis measured with copper and cobalt x-radiation; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
2*	495	Batchelder, D.N., et al.	1968	X	3-24	Ne^{22}	99.35 Ne^{22}, 0.35 Ne^{20}, 0.30 Ne^{21}; similar to the above specimen; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
3	496	Mauer, F.A. and Bolz, L.H.	1961	X	4.2-21.6		Lattice constants measured by an x-ray diffractometer cryostat; temperature accurate to ±0.1 K and lattice constants to ±0.001 Å; lattice constant reported at 4.2 K is 4.4621 Å; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$; 4.4620 Å at 4.0 K used for data conversion.
4	496	Mauer, F.A. and Bolz, L.H.	1961	X	4.2-21.6		The above specimen; another run; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
5	496	Mauer, F.A. and Bolz, L.H.	1961	X	4.2-21.6		The above specimen; another run; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
6	497	Batchelder, D.N.	1965	X	3.5-23.5	Ne^{20}	Natural neon gas 99.995 pure from Air Reduction Co., containing 90.92 Ne^{20}, 0.257 Ne^{21}, and 8.82 Ne^{22}; single crystals grown slowly by Bridgman technique; data smoothed by author from several tests; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
7	497	Batchelder, D.N.	1965	X	3.5-24.5	Ne^{22}	99.36 pure Ne^{22}, 0.35 Ne^{20}, 0.30 Ne^{21}; similar to the above specimen; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
8	498	Bolz, L.H. and Mauer, F.A.	1962	X	4-24	Ne^{20}	Natural neon specimen (90.92 Ne^{20}, 0.26 Ne^{21}, 8.82 Ne^{22}) from commercial source, <0.04 impurity; samples formed by introducing gas into sample chamber at 20 K until deposit 0.1 mm thick; lattice parameter reported at 4.0 K is 4.4619 Å; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
9	498	Bolz, L.H. and Mauer, F.A.	1962	X	4-24	Ne^{20}	Ne^{20} specimen 98.6 pure, 0.1 Ne^{21}, 0.9 Ne^{22}, 0.28 N_2, 0.12 O_2; similar to the above specimen; lattice parameter reported at 4.0 K is 4.4625 Å; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
10	498	Bolz, L.H. and Mauer, F.A.	1962	X	4-24	Ne^{22}	98.83 pure Ne^{22} specimen, 0.85 Ne^{20}, 0.18 Ne^{21}, 0.08 Ar, 0.06 N_2; similar to the above specimen; lattice parameter reported at 4.0 K is 4.4540 Å; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
11	350	Holste, J.C.	1973	L	0.5-14		Specimen length 3 cm; cooled to 4.2 K in 1 hr, in helium atm; data normalized (by 3.6% at most) to agree with accurate x-ray data above 10 K to eliminate sample bonding effects; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

DATA TABLE 29. THERMAL LINEAR EXPANSION OF NEON Ne

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1§

T	$\Delta L/L_0$
3	-0.0010
3.5	-0.0007*
4	0.0000
4.5	0.0011*
5	0.0032*
6	0.0089
7	0.0196*
8	0.0360
9	0.0592*
10	0.0895
11	0.1279*
12	0.1741
13	0.2300*
14	0.2950
15	0.3696*
16	0.4538
17	0.5472*
18	0.6517
19	0.7679*
20	0.8967
21	1.0385*
22	1.1945
23	1.3655*
24	1.5523

CURVE 2§

T	$\Delta L/L_0$
3	-0.0011
3.5	-0.0008*
4	0.0000
4.5	0.0015*
5	0.0035*
6	0.0107
7	0.0226*
8	0.0403
9	0.0650*
10	0.0965
11	0.1359*
12	0.1841
13	0.2420*
14	0.3098
15	0.3872*
16	0.4746
17	0.5723*
18	0.6801
19	0.7988*
20	0.9289
21	1.0713
22	1.2266
23	1.3958*
24	1.5796

CURVE 3§

T	$\Delta L/L_0$
4.2	0.0022
4.8	0.0045
5.2	0.0067*
6.7	0.0202
8.9	0.0762
10.1	0.1210
11.0	0.1546
11.8	0.1972
12.7	0.2532
13.6	0.3160
15.9	0.4818
16.9	0.5625
21.6	1.1183

CURVE 4§

T	$\Delta L/L_0$
4.2	0.0022*
13.3	0.2779
15.4	0.4662
16.1	0.5087
17.1	0.6141
18.1	0.6813
20.4	0.9839
21.6	1.1183*

CURVE 5§

T	$\Delta L/L_0$
4.2	0.0022*
5.5	0.0090
5.8	0.0090*
6.4	0.0112
7.2	0.0247
7.8	0.0359
8.6	0.0515
9.3	0.0896
10.1	0.1143
10.7	0.1390
12.2	0.2017
13.3	0.2958
15.0	0.4101
17.3	0.6051
19.5	0.8561
20.6	1.0197
21.6	1.1183*

CURVE 6§

T	$\Delta L/L_0$
3.5	-0.0008*
4.0	0.0000*
4.5	0.0013
5.0	0.0032
6.0	0.0095*
7.0	0.0200
8.0	0.0361*
9.0	0.0589
10.0	0.0889*
11.0	0.1271
12.0	0.1739*
13.0	0.2300
14.0	0.2955*
15.0	0.3716
16.0	0.4571*
17.0	0.5517
18.0	0.6564*
19.0	0.7732
20.0	0.9021*
21.0	1.0437
22.0	1.1984*
23.0	1.3667
23.5	1.4560

CURVE 7§

T	$\Delta L/L_0$
3.5	-0.0008*
4.0	0.0000*
4.5	0.0014
5.0	0.0035
6.0	0.0107*
7.0	0.0226
8.0	0.0403*
9.0	0.0646
10.0	0.0962*
11.0	0.1359
12.0	0.1843*
13.0	0.2422
14.0	0.3098*
15.0	0.3872
16.0	0.4746*
17.0	0.5723
18.0	0.6801*
19.0	0.7988
20.0	0.9289*
21.0	1.0713
22.0	1.2266*
23.0	1.3958
23.5	1.4856
24.0	1.5796*
24.5	1.6778

CURVE 8§

T	$\Delta L/L_0$
4.0	0.0000*
4.1	0.0022*
4.2	0.0090*
4.7	0.0045*
6.4	0.0112*
6.7	0.0224*
6.9	0.0314
7.1	0.0224*
7.7	0.0381
8.5	0.0538*
8.9	0.0762*
9.3	0.0896*
10.0	0.1121
10.1	0.1165*
10.8	0.1524
11.0	0.1569*
11.6	0.1972
12.1	0.2017*
12.7	0.2533*
13.2	0.2846
13.3	0.2936*
15.3	0.4213
15.3	0.4707*
15.8	0.4819*
16.0	0.5088*
16.8	0.5625*
17.0	0.6163*
17.2	0.6118*
18.0	0.6880*
20.4	0.9929*
20.6	1.0242*
21.6	1.1273

CURVE 9§

T	$\Delta L/L_0$
4.0	0.0000*
5.4	-0.0089*
5.8	0.0022
6.0	0.0156*
6.1	0.0246
8.1	0.0560
9.5	0.1030
10.5	0.1187
10.5	0.1366
11.0	0.1815
12.7	0.2845
13.4	0.3338
13.6	0.3114*
14.2	0.3764
14.4	0.3943
14.5	0.3831
15.2	0.4056
16.0	0.5266
17.7	0.6700
18.6	0.7731
20.5	1.0352
20.6	1.0352*
20.9	1.0173*
21.8	1.1809
22.8	1.3826
22.9	1.3647*
24.0	1.5910
24.0	1.6044

CURVE 10§

T	$\Delta L/L_0$
4.0	0.0000*
4.2	0.0022
5.2	0.0022
5.4	0.0022*
6.4	0.0089*
6.4	0.0112
7.8	0.0381
8.7	0.0516
9.0	0.0583*
9.9	0.0965*
9.9	0.1055*
10.0	0.1077*
10.4	0.1189*
10.5	0.1324
10.7	0.1145*
10.7	0.1234*
12.5	0.2290
12.5	0.2424*
13.0	0.2537*
13.1	0.2604*
13.9	0.3008
13.9	0.3098*
14.2	0.3659*
14.3	0.3659
14.8	0.4220*
15.1	0.4220*
15.1	0.4333*
15.7	0.4804
16.7	0.5657
16.8	0.5859*
17.8	0.6735
18.5	0.7903*
18.6	0.7745
18.6	0.7903*
19.7	0.9137
20.7	1.0395
20.7	1.0597*
21.0	1.1360*
21.1	1.1270*
21.5	1.1989
21.5	1.2101*
22.2	1.299*
22.7	1.3785
22.7	1.3964*
23.3	1.4897
23.8	1.6052*
23.8	1.6142

CURVE 11§

T	$\Delta L/L_0$
0.5	-0.001876
1.0	-0.001870
1.5	-0.001843
2.0	-0.001769
2.5	-0.001610

* Not shown in figure.

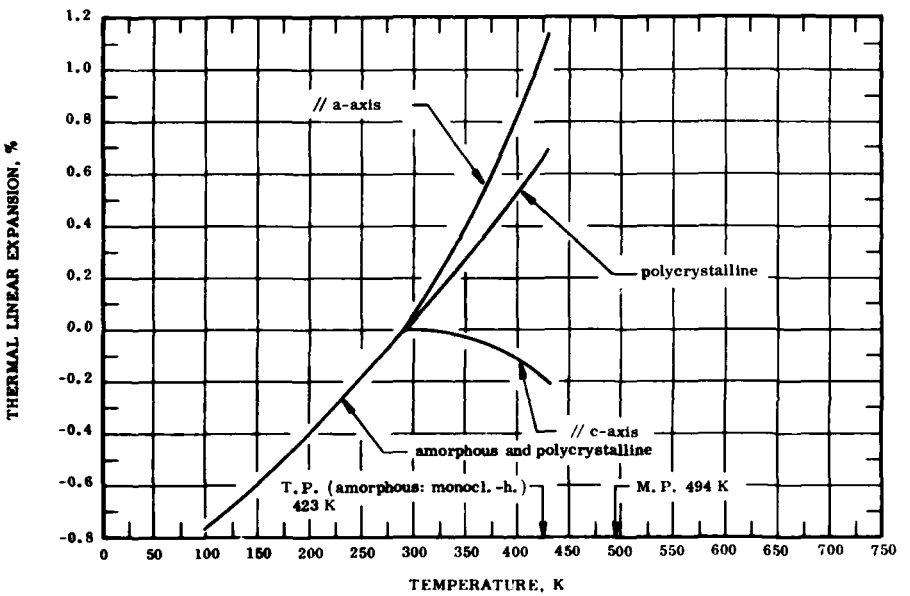
§ This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 29. THERMAL LINEAR EXPANSION OF NEON Ne (continued)

T	$\Delta L/L_0$
CURVE 11 (cont.)§	
3.0	-0.001314*
3.5	-0.000809
4.0	0.000000*
4.5	0.001234*
5.0	0.003034*
5.5	0.005567*
6.0	0.009003*
6.5	0.01350*
7.0	0.01923*
7.5	0.02633
8.0	0.03497*
8.5	0.04528*
9.0	0.05739*
9.5	0.07141
10.0	0.08741*
11.0	0.1254*
12.0	0.1724*
13.0	0.2286*
14.0	0.2937*

* Not shown in figure.
§ This curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.

FIGURE AND TABLE NO. 30R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SELENIUM Se



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	(Hexagonal structure)				
	// a-axis	// c-axis	Amorphous	Polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
100			-0.768	-0.768	34.0
150			-0.584	-0.584	37.5
200			-0.392	-0.382	39.6
250			-0.187	-0.187	43.0
293	*0.000*	*0.000*	*0.000*	*0.000*	*45.0*
350	0.410	-0.040		0.269	49.5
400	0.820	-0.115		0.527	54.0
430	1.140	-0.200		0.693	57.1

REMARKS

The recommended values for the axial thermal expansion for the sample of hexagonal structure are based on the data reported in curves 1 and 2. The values for amorphous and polycrystalline sample are based on the experimental data (curves 3, 6, 8 and 9) at temperatures below 293 K and those for polycrystalline at temperatures above 293 K are calculated from the axial values. This result is recommended in preference to the reported experimental data for polycrystalline samples (curves 4 and 7) on the suspicion that those samples exhibit preferential orientation and are not randomly oriented. These values are considered accurate to within ± 5% and are represented approximately by the following equations:

// a-axis of hexagonal structure: $\Delta L/L_0 = -7.556 + 0.057\ T - 1.537 \times 10^{-4}\ T^2 + 1.564 \times 10^{-7}\ T^3$

// c-axis of hexagonal structure: $\Delta L/L_0 = 2.197 - 0.020\ T + 6.263 \times 10^{-5}\ T^2 - 6.720 \times 10^{-8}\ T^3$

Amorphous: $\Delta L/L_0 = -1.123 + 3.520 \times 10^{-3}\ T - 1.706 \times 10^{-7}\ T^2 + 4.205 \times 10^{-9}\ T^3$

Polycrystalline: $\Delta L/L_0 = -1.123 + 3.520 \times 10^{-3}\ T - 1.706 \times 10^{-7}\ T^2 + 4.205 \times 10^{-9}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 5%.

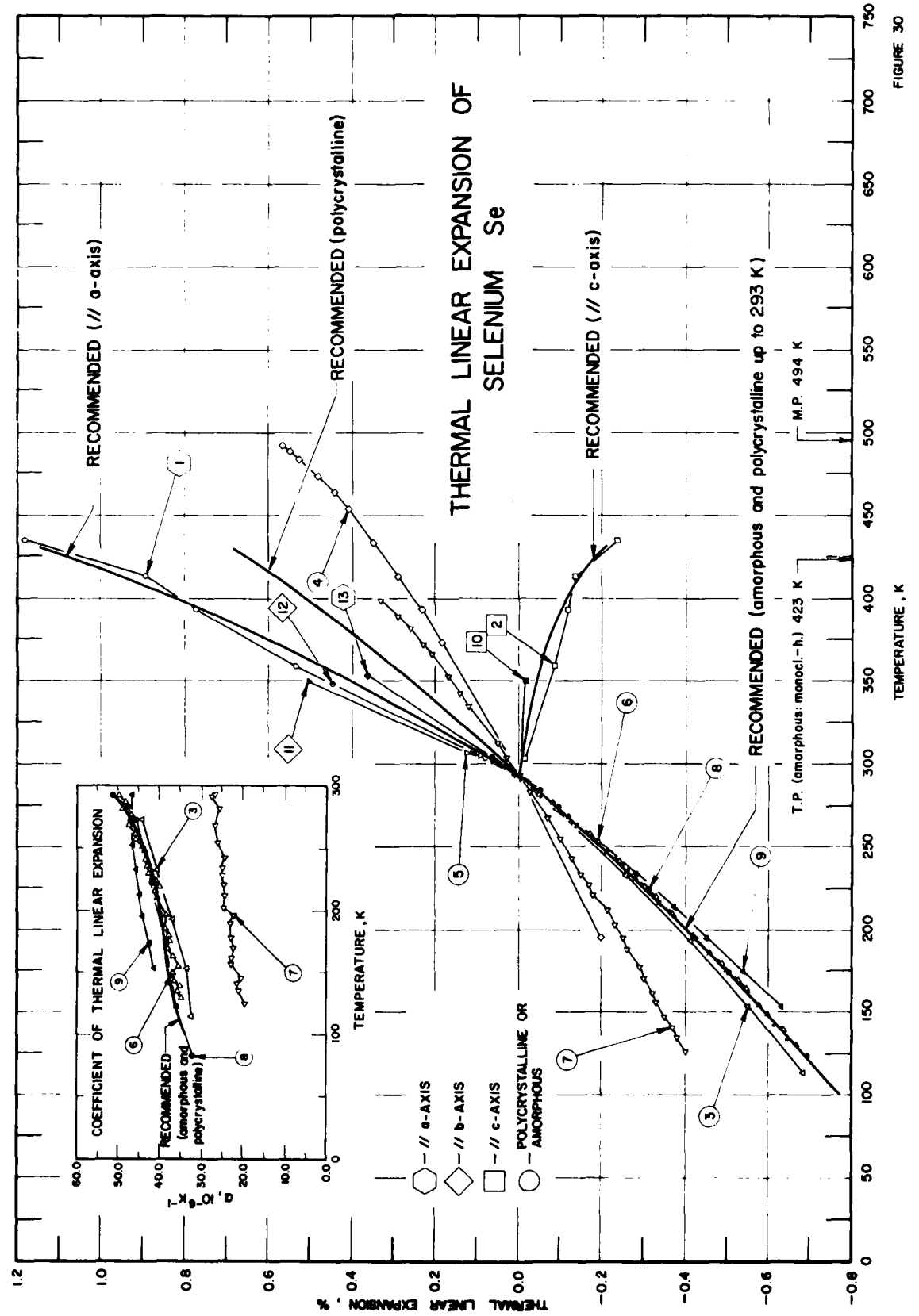

THERMAL LINEAR EXPANSION OF SELENIUM Se
RECOMMENDED (// a-axis)
RECOMMENDED (polycrystalline)
RECOMMENDED (// c-axis)
RECOMMENDED (amorphous and polycrystalline up to 293 K)
T.P. (amorphous: monocl.→h.) 423 K
M.P. 494 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
// a-AXIS
// b-AXIS
// c-AXIS
POLYCRYSTALLINE OR AMORPHOUS
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED (amorphous and polycrystalline)
α , 10⁻⁶ K⁻¹

FIGURE 30

SPECIFICATION TABLE 30. THERMAL LINEAR EXPANSION OF SELENIUM Se

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	499	Deshpande, V.T.	1964	X	303-435		Specpure beads of Se from Johnson Matthey crushed to powder and annealed 48 hrs at 453 K, expansion measured along a-axis; lattice parameter reported at 303.2 K is 4.3683 Å; 4.3648 Å at 293.2 K determined by graphical extrapolation.
2	499	Deshpande, V.T.	1964	X	303-435		The above specimen; expansion measured along c-axis; lattice parameter reported at 303.2 K is 4.9548 Å; 4.9554 Å at 293.2 K determined by graphical extrapolation.
3	166	Dorsey, H.G.	1908	I	113-273		Amorphous specimen 0.8561 cm long; obtained from Eimer and Amend; melted in platinum crucible and cast in thin sheet zinc mold, zinc then dissolved in dilute H_2SO_4; no apparent formation of selenide.
4	500	Borelius, G. and Paulson, K.A.	1946	L	195-492		99.99 pure polycrystalline specimen crystallized at 353 K, then recrystallized at 488 K.
5	500	Borelius, G. and Paulson, K.A.	1946	L	195-307		Amorphous specimen 99.99 pure, rapidly cooled.
6	501	Chistov, S.F., Chernov, A.P., and Dombovskii, S.A.	1968	L	130-293		Vitreous specimen, cooled to temperature of liquid nitrogen and heated at a rate of 1.6 degrees per min.
7	501	Chistov, S.F., et al.	1968	L	126-398		Polycrystalline specimen obtained by heating vitreous Se at 433 K for 5 days; specimen cooled to temperature of liquid nitrogen and heated at a rate of 1.6 degrees per min.
8	535	Kirby, R.K. and Rothrock, B.D.	1968	L	83-303		99.99 pure vitreous rod specimen, 6 mm diameter; ends of specimen was ground to spherical shape resulting length of 11.4 mm in room temperature; glass transition temperature at 303 K; density 4.26 g cm^{-3} at 298 K; coefficient of linear expansion also reported.
9	536	Felty, E.J. and Myers, M.B.	1967		153-293		99.9999 pure vitreous specimen.
10	537	Hawton, C.J. and Colby, M.Y.	1951	X	293-350		α-monoclinic crystal specimen with particle size ranging from that of fine powder to 1 mm greatest dimension obtained from saturated solution of carbon disulfide; plane spacing measured along c-axis; 9.0440 kX reported at 293.2 K.
11	537	Hawton, C.J. and Colby, M.Y.	1951	X	293-350		The above specimen; plane spacing measured along b-axis; 9.0545 kX reported at 293.2 K.
12	537	Hawton, C.J. and Colby, M.Y.	1951	X	293-348		The above specimen; second measurement along b-axis; 9.0546 kX reported at 293.2 K.
13	537	Hawton, C.J. and Colby, M.Y.	1951	X	294-353		The above specimen; plane spacing measured along a-axis; 11.573 kX reported at 294.2 K.

DATA TABLE 30. THERMAL LINEAR EXPANSION OF SELENIUM Se

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
303	0.0801
359	0.5361
393	0.7766
413	0.8980
435	1.1821
CURVE 2	
303	-0.0121
359	-0.0827
393	-0.1190
413	-0.1352
435	-0.2280
CURVE 3‡	
113	-0.687
153	-0.555
193	-0.414
233	-0.259
273	-0.090
CURVE 4	
195	-0.199
293	0.000
373	0.183
393	0.235
413	0.289
433	0.347
453	0.410
463	0.441
473	0.481
483	0.526
488	0.550
492	0.570
CURVE 5	
195	-0.422
273	-0.089*
282	-0.057
287	-0.035
291	-0.011
292	-0.006
294	0.005
295	0.011
CURVE 5 (cont.)	
298	0.029
302	0.061
304	0.082*
305	0.092
307	0.122
CURVE 6‡	
130	-0.67
134	-0.65
139	-0.64
143	-0.62
149	-0.60
154	-0.58
164	-0.55
169	-0.53
175	-0.50
180	-0.49
186	-0.46
196	-0.42
210	-0.37
216	-0.34
220	-0.33
226	-0.30
231	-0.28
236	-0.26
242	-0.24
247	-0.21
253	-0.19
258	-0.17
263	-0.14
268	-0.12
277	-0.08
282	-0.05
287	-0.03
293	0.00*
CURVE 7‡	
126	-0.40
135	-0.38
141	-0.37
147	-0.35
156	-0.33
162	-0.32
170	-0.30
177	-0.29
CURVE 7 (cont.)‡	
188	-0.26
195	-0.25
203	-0.23
212	-0.21
221	-0.18
227	-0.17
234	-0.15
243	-0.13
255	-0.10
268	-0.07
283	-0.03
292	0.00*
293	0.00*
304	0.03
312	0.05
335	0.12
342	0.14
353	0.17
366	0.21
372	0.23
382	0.26
389	0.29
398	0.33
CURVE 8	
83	-0.832*
123	-0.694
173	-0.509
223	-0.310
273	-0.095
283	-0.049
293	0.000*
298	0.029*
303	0.067
CURVE 9‡	
153	-0.63
173	-0.54
194	-0.45
213	-0.37
233	-0.28
253	-0.19*
274	-0.09
293	0.00
CURVE 10	
293.2	0.0000*
350.5	-0.0144
CURVE 11	
293.2	0.0000*
350.5	0.5058
CURVE 12	
293.2	0.0000*
348.4	0.4506
CURVE 13	
294.2	0.0000*
353.4	0.3629

*Not shown in figure.

‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 30. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SELENIUM Se

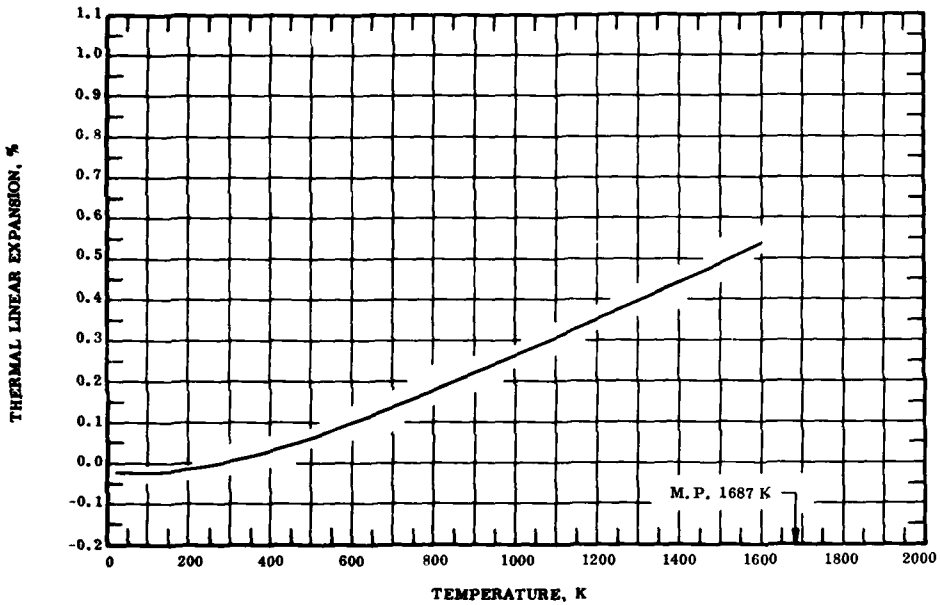
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3‡	
113	32.5
153	33.5
193	37.0
233	40.6
273	44.0
CURVE 6‡	
130	34.8
134	35.9
139	35.1
143	36.4
149	36.7
154	35.4
164	36.7
169	37.9
175	37.5
180	37.8
186	38.5
196	38.5
210	40.5
216	40.9
220	40.0
226	40.9
231	42.4
236	42.8
242	43.3
247	43.5
253	43.8
258	45.5
263	43.5
268	47.3
277	46.8
282	48.9
287	48.0
293	50.0
CURVE 7‡	
126	19.6
135	20.6
141	21.2
147	20.4
156	22.6
162	22.6
170	22.1
CURVE 7 (cont.)‡	
177	22.6
188	23.0
195	22.2
203	24.5
212	24.2
221	24.6
227	25.0
234	25.0
243	24.3
255	25.9
268	26.5
283	25.7
292	27.2
293	26.4
304	27.9*
312	28.0*
335	27.5*
342	29.7*
353	29.6*
366	31.6*
372	34.7*
382	36.2*
389	40.9*
398	41.8*
CURVE 8	
83	32.4
123	36.1
173	38.6
223	41.3
273	45.5
283	47.4
293	51.3
298	65.6*
303	93.0*
CURVE 9‡	
153	41.4
173	42.8
194	44.0
213	44.7
233	45.9
253	46.3
274	46.7
293	46.3

*Not shown in figure.

‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/l_0$.

FIGURE AND TABLE NO. 31R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SILICON Si



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
20	-0.022	0.0
25	-0.022	0.0
50	-0.022	-0.2
75	-0.023	-0.5
100	-0.024	-0.4
150	-0.024	0.5
200	-0.019	1.5
250	-0.010	2.2
293	0.000	2.6
400	0.033	3.2
500	0.066	3.5
600	0.102	3.7
700	0.141	3.9
800	0.181	4.1
900	0.223	4.3
1000	0.266	4.4
1200	0.356	4.6
1400	0.448	4.6
1600	0.540	4.7

REMARKS

The recommended values are based on the data for pure samples and are considered accurate to within ± 3%. These values are represented approximately by the following equations:

$$\Delta L/L_0 = -0.021 - 4.149 \times 10^{-5}\, T - 4.620 \times 10^{-8}\, T^2 + 1.482 \times 10^{-9}\, T^3 \qquad (20\text{–}293\ K)$$

$$\Delta L/L_0 = -0.071 + 1.887 \times 10^{-4}\, T + 1.934 \times 10^{-7}\, T^2 - 4.544 \times 10^{-11}\, T^3 \qquad (293\text{–}1600\ K)$$

The tabulated values for the coefficient of thermal expansion are derived from the experimental data (curves 3, 8, 22 and 23) and are considered accurate to about ± 5%.

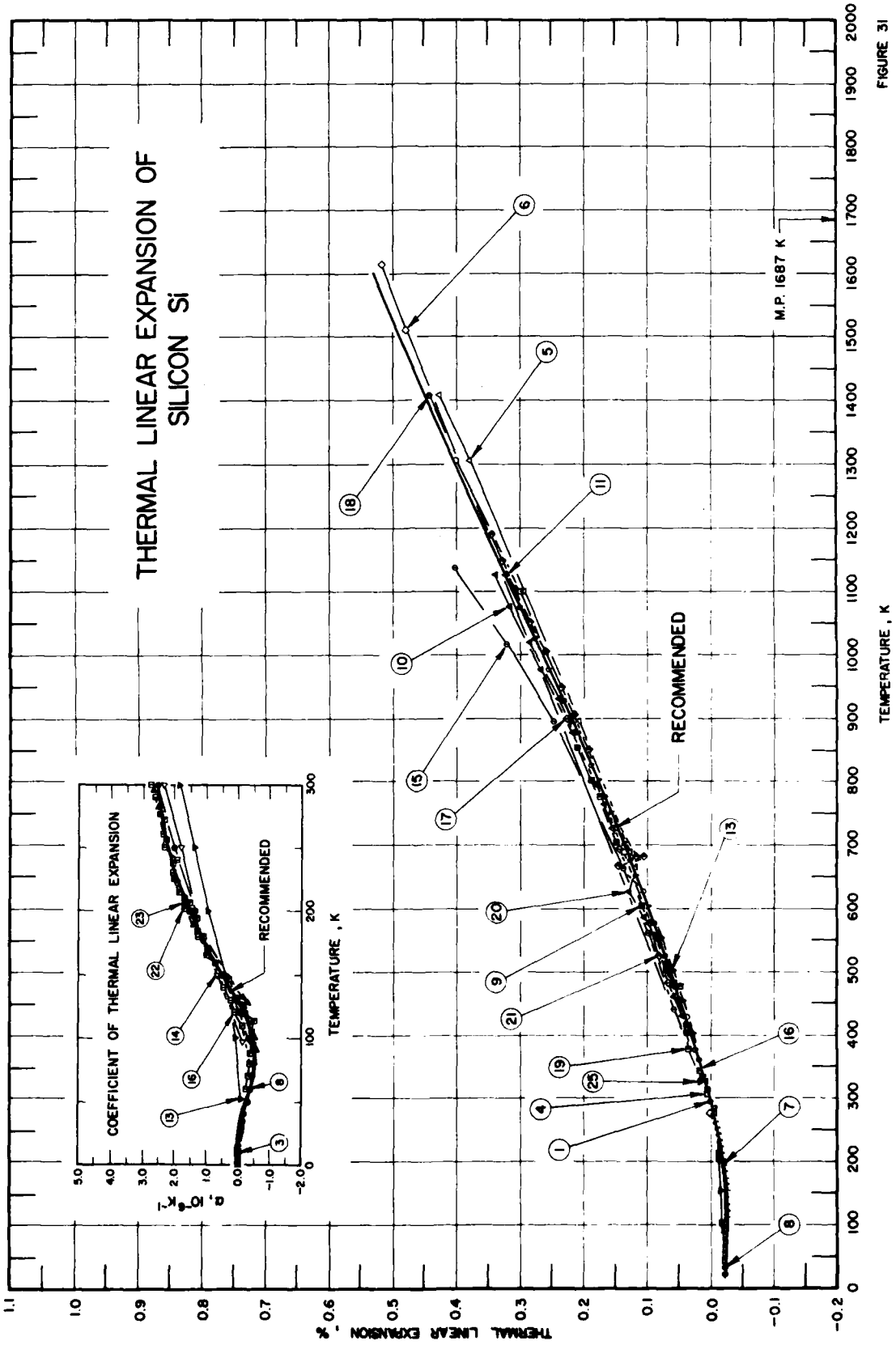

THERMAL LINEAR EXPANSION OF SILICON Si
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
M.P. 1687 K
RECOMMENDED
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K
RECOMMENDED

FIGURE 31

SPECIFICATION TABLE 31. THERMAL LINEAR EXPANSION OF SILICON Si

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	505	Zhdanova, V.V., Kekua, M.G., and Samadashvill, T.Z.	1967	L	293-1073		Pure Si; specimen 0.1 to 0.8 mm in cross-section, and 1.0 to 2.7 mm in length; expansion measured in vacuum; reported error 1-3%.
2*	506	Carr, R.H., McCammon, R.D., and White, G.K.	1965	C	2.6-15		Specimen cylinder oriented parallel to (111) direction; crystal supplied by DuPont de Nemours and Co.; N-type crystal; resistivity 100 to 150 ohm cm; this curve is here reported using the first given temperature (2.64 K) as reference temperature at which $\Delta L/L_0 = 0$.
3*	460	Sparks, P.W. and Swenson, C.A.	1967	V	2-30		Specimen 0.9 cm diameter, 13.65 cm long at 4 K; obtained from Texas Instruments; tested as received; this curve is here reported using 4 K as reference temperature at which $\Delta L/L_0 = 0$; coefficients of linear expansion also reported.
4	10	Mauer, F.A. and Bolz, L.H.	1955	X	273-1303		>99.98 pure; specimen obtained from Bell Telephone Laboratories; sintered at 1323 K; expansion measured in helium atmosphere; zero-point correction of -0.006% determined by graphical interpolation.
5	10	Mauer, F.A. and Bolz, L.H.	1955	X	1406-273		99.97 pure; specimen obtained from duPont; sintered in vacuo at 1406 K; expansion measured in vacuo with decreasing temperature; zero-point correction of -0.006% determined by graphical interpolation.
6	10	Mauer, F.A. and Bolz, L.H.	1957	X	273-1612		Similar to the above specimen; expansion measured with increasing temperature.
7	507	Gibbons, D.F.	1958	I	40-300		Three crystals prepared; one grown by crystal-pulling technique and rotated during growth, contained electrically active impurities concentration 10^{15} cm^{-3}; two crystals prepared with expansion measured in (100) and (111) growth directions; second crystal grown as above but without rotation; expansion measured along (100) direction; third crystal grown by floating-zone technique with impurity concentration of 2×10^{13} cm^{-3}; expansion measured along (100) direction; data given average of results on three specimens showing no difference in experimental results; zero-point correction of -0.0046% determined by graphical interpolation.
8	508	Ibach, H.	1969	E	20-300		Specimen prepared from a zone-melted silicon rod (2000 Ω cm); density of dislocations about 10^3 cm^{-2}.
9	508	Ibach, H.	1969	I	300-850		Similar to the above specimen.
10	509	Maissel, L.	1960	O	323-1123		Specimen 5 cm long, 0.32 cm square; expansion data average of results on several specimens; expansion measured along (111) orientation.
11	509	Maissel, L.	1960	O	323-1123		Similar to the above specimen except expansion measured along (110) orientation.
12*	324	Batchelder, D.N. and Simmons, R.O.	1964		6-322		Specimen cut from bar of n-type floating-zone-refined material having resistivity 20 Ω cm; (111) oriented crystal face 2.5 x 11 mm x ~0.8 mm thick, polished, etched; one end electroless nickel plated, then soldered to invar block in cryostat; data combination of results on two separate runs.
13	510	Nasekovs'kii, A.P.	1967		325-1073		High purity specimen.
14*	511	Fine, M.E.	1953		97-426		High purity specimen.

*Not shown in figure.

SPECIFICATION TABLE 31. THERMAL LINEAR EXPANSION OF SILICON Si (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
15	464	Shaw, N. and Liu, Y.H.	1965	X	303-1133		99.9999 purity powder, annealed at 1173 K for 48 hr before high-temperature investigation; lattice parameter reported at 303.2 K is 5.4197 Å; 5.4195 Å at 293.2 K determined by graphical extrapolation.
16	512	Novikova, S.I. and Strelkov, P.G.	1960		22-340		Single crystal specimens pure enough for semiconductor applications; 23.7 x 12.2 x 9.0 mm and 19.2 x 9.7 x 8.9 mm; data combined results for both specimens.
17	513	Mauer, F.A. and Bolz, L.H.	1954	X	298-896		Specimen supplied by Johnson, Matthey and Co., Ltd.; spectrographic analysis indicated 0.001 or less of Cu, Ag, Zn, Sn, Fe, and Mg; zero-point correction of -0.008% determined by graphical extrapolation.
18	513	Mauer, F.A. and Bolz, L.H.	1954	X	298-1405		Specimen supplied by Electro Metallurgical Co. (Lot 33867); 99.7-99.9 purity; zero-point correction of -0.006% determined by graphical extrapolation.
19	514	Hall, R.O.A.	1961	X	293-773		Expansion measured by camera of Unicam S150, Goldschmidt type; lattice parameter reported at 293 K is 5.4303 Å.
20	514	Hall, R.O.A.	1961	X	293-1018		The above specimen; expansion measured by modified camera; lattice parameter reported at 293 K is 5.4300 Å.
21	515	Burkhardt, P.J. and Marvel, R.F.	1969		293-1186		Cathetometer used to measure distance between two reference marks as function of temperature on freely suspended strip of film; measurement had range of 50 mm, sensitivity of 0.001 mm.
22*	516	Novikova, S.I.	1964		81-343	p-type	Pure silicon with carrier concentration of $\sim 10^{17}$ cm^{-3}.
23*	516	Novikova, S.I.	1964		91-315	n-type	Pure silicon with carrier concentration of $\sim 10^{19}$ cm^{-3}.
24*	517	Birss, R.R. and Horne, R.J.	1960		79-394		Rod single crystal 2.3 cm long with its long axis parallel to (111) crystallographic direction; zero-point correction of -0.0047%.
25	518	Straumanis, M.E. and Aka, E.Z.	1952	X	283-323		99.97 pure specimen containing 0.03 C, received from duPont Co.; density 2.3283 g cm^{-3} at 293 K; powder mount about 0.12 mm diameter; lattice parameter reported at 293.2 K is 5.41984 kX.
26*	519	Bhalla, A.S. and White, E.W.	1971	X	298-314		No details given; zero-point correction of -0.0012% determined by graphical extrapolation.
27*	520	Shah, J.S. and Straumanis, M.E.	1972	X	40-180		99.999 pure powder from Koch Labs, England; particle size of 20 μ or less; lattice parameter reported at 40 K is 5.42955 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
28*	504	Yim, W.M. and Paff, R.J.	1973	X	298-1086		Lattice parameter was determined by a precision high temperature x-ray camera (Unicam Model S-150) evacuated to 10^{-3} torr; at 293 K the lattice parameter was given as 5.4308 Å.
29*	585	White, G.K.	1973	E	20-283		Specimen 2.2 cm diameter and 5.08 cm long 100 Ω/cm N-type obtained from Merck, Sharp and Dohme plated with Ca; 0.002 cm of nickel (1967-1968) and later (1969) with layer of evaporated silver, thermal aged by Dr. G. Hetherington of Thermal Syndicate Ltd.

*Not shown in figure.

DATA TABLE 31. THERMAL LINEAR EXPANSION OF SILICON Si

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
293	0.000
356	0.017
373	0.022
426	0.038
473	0.054
523	0.071
573	0.088
623	0.106
673	0.126
723	0.146
773	0.166
823	0.187
873	0.207
923	0.229
973	0.252
1023	0.275
1073	0.299
CURVE 2*,†	
2.64	0.00
8.52	0.51
9.78	0.45
10.29	0.57
11.73	0.80
12.46	0.93
13.18	1.05
13.95	1.14
14.90	1.28
15.46	1.19
CURVE 3*,§	
1.89	-0.0036×10^{-6}
2.30	-0.0036
2.71	-0.0036
3.10	-0.0036
3.45	-0.0014
3.86	-0.0014
4.23	0.0023
4.58	0.0059
4.76	0.0059
5.11	0.0103
5.44	0.0140
5.77	0.0184
6.10	0.0228
CURVE 3 (cont.)*,§	
6.42	0.0308×10^{-6}
6.74	0.0389
7.05	0.0477
7.24	0.0536
7.55	0.066
7.85	0.081
8.16	0.095
8.46	0.11
8.77	0.13
9.07	0.15
9.36	0.16
9.51	0.18
9.81	0.20
10.10	0.23
10.40	0.26
10.69	0.28
10.98	0.32
11.28	0.36
11.57	0.39
11.71	0.41
12.07	0.47
12.42	0.53
12.79	0.59
13.15	0.65
13.51	0.73
13.90	0.82
14.26	0.88
14.62	0.96
14.98	1.1
15.35	1.2
15.71	1.3
16.07	1.4
17.90	1.8
18.26	1.8
19.00	1.8
20.46	1.5
22.12	0.53
22.48	0.24
24.07	-1.8
24.42	-2.3
26.11	-6.6
26.44	-7.6
28.03	-15.0
28.22	-16.0
28.35	-16.0
29.86	-27.0
30.16	-29.0
CURVE 4	
273	-0.006
303	0.003
479	0.058
685	0.136
891	0.214
1097	0.297
1303	0.399
CURVE 5	
1406	0.424
1303	0.377
1097	0.292
891	0.207
685	0.128
479	0.056
298	0.001
273	-0.006
CURVE 6	
273	0.000
298	0.000
1509	0.477
1612	0.515
CURVE 7	
40	-0.0214
50	-0.0215
60	-0.0218
70	-0.0223
80	-0.0230
90	-0.0238
100	-0.0241
110	-0.0244
120	-0.0245
130	-0.0243
140	-0.0241
150	-0.0237
160	-0.0232
170	-0.0224
180	-0.0215
190	-0.0203
200	-0.0189
210	-0.0173
CURVE 7 (cont.)	
220	-0.0157
230	-0.0139
240	-0.0116
250	-0.0098
260	-0.0076
270	-0.0053
280	-0.0031
290	-0.0007
300	0.0016
CURVE 8‡	
20	-0.0213
22	-0.0214
24	-0.0214
26	-0.0214
28	-0.0214
30	-0.0214
35	-0.0214
40	-0.0215
50	-0.0217
60	-0.0220
70	-0.0224
80	-0.0228
100	-0.0237
120	-0.0240
150	-0.0233
200	-0.0185
250	-0.0099
300	0.0016
CURVE 9‡	
400	0.036
500	0.070
600	0.107
700	0.147
800	0.187
850	0.207
CURVE 10	
323	0.0075
373	0.0200
473	0.0510
573	0.086
CURVE 10 (cont.)	
673	0.125
773	0.168
873	0.215
973	0.265
1073	0.314
1123	0.337
CURVE 11	
323	0.0081
373	0.0216
473	0.0516
573	0.0856
673	0.1236
773	0.165
873	0.209
973	0.254
1073	0.299
1123	0.320
CURVE 12*	
6.4	-0.02184
6.4	-0.02185
6.4	-0.02200
11.7	-0.02172
17.4	-0.02173
19.6	-0.02120
20.6	-0.02139
24.3	-0.02149
26.6	-0.02207
26.8	-0.02158
30.5	-0.02138
35.2	-0.02200
39.8	-0.02176
41.0	-0.02160
44.9	-0.02204
47.8	-0.02161
51.6	-0.02191
56.6	-0.02259
60.9	-0.02289
72.2	-0.02327
77.4	-0.02314
78.7	-0.02340
83.4	-0.02401
89.1	-0.02379
CURVE 12 (cont.)*	
95.0	-0.02428
95.6	-0.02416
99.3	-0.02491
103.1	-0.02423
110.8	-0.02405
115.8	-0.02451
120.2	-0.02478
122.1	-0.02400
127.5	-0.02476
133.4	-0.02425
136.2	-0.02443
141.1	-0.02425
144.3	-0.02335
150.3	-0.02377
153.4	-0.02333
158.6	-0.02333
162.9	-0.02289
171.3	-0.02259
177.6	-0.02215
180.6	-0.02180
189.0	-0.02072
190.9	-0.02003
198.9	-0.01898
205.8	-0.01854
213.2	-0.01736
218.5	-0.01644
229.0	-0.01478
236.8	-0.01386
239.2	-0.01324
243.4	-0.01224
247.7	-0.01163
252.0	-0.01003
257.7	-0.00930
261.9	-0.00806
267.2	-0.00666
272.9	-0.00570
278.2	-0.00454
282.6	-0.00350
287.6	-0.00174
293.5	0.00009
297.4	0.00053
299.1	0.00117
304.8	0.00294
308.3	0.00336
312.8	0.00497
319.0	0.00629
322.5	0.00714

*Not shown in figure.

†This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

§This curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 31. THERMAL LINEAR EXPANSION OF SILICON Si (continued)

T	$\Delta L/L_0$
CURVE 13‡	
52	-0.018
100	-0.018
150	-0.016
200	-0.013
250	-0.007
300	0.001
350	0.012
400	0.026
450	0.042
500	0.059
550	0.078
600	0.097
650	0.116
700	0.135
750	0.154
800	0.174
CURVE 14*, ‡	
97	-0.023
150	-0.022
200	-0.017
250	-0.009
300	0.001
350	0.014
400	0.029
426	0.037
CURVE 15	
303	0.0036
439	0.0572
558	0.0977
660	0.1383
891	0.2454
1013	0.3192
1133	0.4004
CURVE 16‡	
26.4	-0.024
28.8	-0.024
30.3	-0.024
35.1	-0.024
37.5	-0.024
39.5	-0.024
44.3	-0.024

T	$\Delta L/L_0$
CURVE 16 (cont.)‡	
46.8	-0.025
49.3	-0.025
53.5	-0.025
56.1	-0.025
59.1	-0.025
61.0	-0.025
63.5	-0.025
67.8	-0.025
70.1	-0.025
71.0	-0.025
72.9	-0.025
75.2	-0.025
78.0	-0.025
80.8	-0.026
83.5	-0.026
84.4	-0.026
86.5	-0.026
90.6	-0.026
92.5	-0.026
93.2	-0.026
93.8	-0.026
97.3	-0.026
98.5	-0.026
101.8	-0.026
106.9	-0.026
110.1	-0.026
114.6	-0.026
118.1	-0.026
118.6	-0.026
123.9	-0.026
127.5	-0.026
130.9	-0.026
137.4	-0.026
139.1	-0.026
145.3	-0.026
146.3	-0.026
151.9	-0.025
154.3	-0.025
156.1	-0.025
163.2	-0.024
164.5	-0.024
171.4	-0.024
174.5	-0.023
178.1	-0.023
183.4	-0.022
186.7	-0.022
192.2	-0.021

T	$\Delta L/L_0$
CURVE 16 (cont.)‡	
194.1	-0.021
201.4	-0.020
201.4	-0.020
203.2	-0.019
209.1	-0.018
209.7	-0.018
211.7	-0.018
217.3	-0.017
217.3	-0.017
224.9	-0.016
226.1	-0.015
232.5	-0.014
235.7	-0.013
241.7	-0.012
242.9	-0.012
245.2	-0.011
248.5	-0.011
252.9	-0.010
253.9	-0.010
256.0	-0.009
262.1	-0.008
264.4	-0.007
271.6	-0.005
272.3	-0.005
274.2	-0.005
279.8	-0.003
282.2	-0.003
286.2	-0.002
291.1	-0.001
294.2	0.000
301.8	0.002
303.0	0.003
309.4	0.004
311.0	0.005
316.9	0.007
319.5	0.007
320.4	0.008
322.4	0.008
324.6	0.009
329.7	0.010
331.8	0.011
339.5	0.013
CURVE 17	
298	0.002
480	0.067

T	$\Delta L/L_0$
CURVE 17 (cont.)	
690	0.141
896	0.224
CURVE 18	
298	0.001
480	0.062
685	0.132
895	0.215
1101	0.305
1303	0.399
1405	0.440
CURVE 19	
293	0.0000
333	0.0147
373	0.0331
477	0.0478
566	0.0883
773	0.1712
CURVE 20	
293	0.0000
304	0.0018
314	0.0055
327	0.0110
340	0.0165
361	0.0220
391	0.0313
427	0.0441
459	0.0570
497	0.0681
582	0.1049
622	0.1289
662	0.1197
691	0.1436
725	0.1528
760	0.1675
791	0.1786
850	0.2025
926	0.2394
1018	0.2817

T	$\Delta L/L_0$
CURVE 21	
293	0.0000
322	0.0125
346	0.0181
364	0.0246
406	0.0396
458	0.0448
483	0.0588
498	0.0559
523	0.0867
573	0.0995
631	0.1097
664	0.1435
679	0.1043
679	0.1176
737	0.1481
792	0.1754
848	0.1906
903	0.2127
945	0.2332
1003	0.2594
1049	0.2822
1111	0.3078
1145	0.3270
1186	0.3439
CURVE 22*, ‡	
81	-0.024
88	-0.025
95	-0.025
105	-0.025
114	-0.026
119	-0.026
131	-0.026
147	-0.026
165	-0.024
180	-0.023
184	-0.022
194	-0.021
201	-0.020
206	-0.019
218	-0.017
225	-0.016
237	-0.013
257	-0.009
272	-0.005
277	-0.004

T	$\Delta L/L_0$
CURVE 22 (cont.)*, ‡	
293	0.000
301	0.002
322	0.008
343	0.014
CURVE 23*, ‡	
91	-0.024
103	-0.025
125	-0.025
128	-0.025
128	-0.025
131	-0.025
152	-0.025
170	-0.024
188	-0.022
206	-0.019
282	-0.003
293	0.000
295	0.000
315	0.006
CURVE 24*	
79	-0.0262
84	-0.0265
93	-0.0271
104	-0.0271
113	-0.0271
124	-0.0271
133	-0.0271
143	-0.0267
154	-0.0262
163	-0.0256
173	-0.0249
184	-0.0237
193	-0.0225
204	-0.0208
213	-0.0191
225	-0.0166
233	-0.0144
244	-0.0118
253	-0.0096
264	-0.0068
273	-0.0047
283	-0.0025
293	0.0000

*Not shown in figure.

‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 31. THERMAL LINEAR EXPANSION OF SILICON Si (continued)

T	$\Delta L/L_0$
CURVE 24 (cont.)*	
303	0.0026
312	0.0048
323	0.0075
334	0.0101
343	0.0122
353	0.0143
364	0.0172
373	0.0195
384	0.0218
394	0.0245
CURVE 25	
283	-0.00332
293	0.00000
303	0.00461
313	0.00830
323	0.01328
CURVE 26*	
298	0.0018
302	0.0021
306	0.0030
310	0.0040
314	0.0049
CURVE 27*,†	
40	0.0000
60	-0.0007
80	-0.0018
100	-0.0028
140	-0.0024
159	-0.0014
180	-0.0000
CURVE 28*	
298	0.0018
430	0.0442
629	0.1142
769	0.1657
924	0.2228
1086	0.2817

T	$\Delta L/L_0$
CURVE 29*,‡	
20	-0.021
30	-0.021
40	-0.021
57	-0.021
65	-0.021
75	-0.022
85	-0.022
95	-0.023
105	-0.023
115	-0.023
125	-0.023
135	-0.023
199	-0.018
207	-0.017
283	-0.002

*Not shown in figure.

†This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡Author's data for coefficient of thermal expansion have been integraged by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 31. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SILICON Si

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1*,‡	
293	2.53
356	2.92
373	3.00
426	3.16
473	3.30
523	3.45
573	3.62
623	3.72
673	3.85
723	3.99
773	4.15
823	4.23
873	4.35
923	4.47
973	4.57
1023	4.68
1073	4.79
CURVE 3	
0	0.000000
2	0.000007
4	0.000056
6	0.000192
8	0.00045
10	0.00088
12	0.00152
14	0.00242
16	0.0032
18	0.0018*
20	-0.0025*
22	-0.0065*
24	-0.0122*
26	-0.0190*
28	-0.0268*
30	-0.0360*
32	-0.0475*
CURVE 8‡	
20	-0.005
22	-0.0085
24	-0.016
26	-0.026
28	-0.038
30	-0.053
CURVE 8 (cont.)‡	
35	-0.100
40	-0.16
50	-0.28
60	-0.365
70	-0.415
80	-0.465
100	-0.34
120	-0.04
150	0.525
200	1.41
250	2.03
300	2.56
CURVE 9*,‡	
400	3.20
500	3.59
600	3.86
700	3.98
800	4.05
850	4.08
CURVE 13‡	
52	-0.10
100	0.10
150	0.43
200	0.96
250	1.40
300	1.88
350	2.45*
400	3.00*
450	3.42*
500	3.64*
550	3.74*
600	3.81*
650	3.84*
700	3.86*
750	3.91*
800	3.92*
CURVE 14‡	
97	-0.12
150	0.63
200	1.36
250	1.81
300	2.31
350	2.72*
400	3.14*
426	3.32*
CURVE 16‡	
26.4	-0.20
28.8	-0.30
30.3	-0.16
35.1	-0.16
37.5	-0.23
39.5	-0.17
44.3	-0.30
46.8	-0.39
49.3	-0.20
53.5	-0.24
56.1	-0.32
59.1	-0.21
61.0	-0.28
63.5	-0.39
67.8	-0.36
70.1	-0.28
71.0	-0.39
72.9	-0.33
75.2	-0.18
78.0	-0.33
80.8	-0.29
83.5	-0.44
84.4	-0.20
86.5	-0.16
90.6	-0.33
92.5	-0.52
93.2	-0.27
93.8	-0.19
97.3	-0.39
98.5	-0.25
101.8	-0.41
106.9	-0.19
110.1	-0.11
114.6	-0.01
118.1	-0.07
CURVE 16 (cont.)‡	
123.9	0.13
127.5	0.31
130.9	0.22
137.4	0.37
139.1	0.46
145.3	0.54
146.3	0.71
151.9	0.56
154.3	0.73
156.1	0.82
163.2	0.76
164.5	0.93
171.4	0.98
174.5	1.06
178.1	1.28
183.4	1.30
186.7	1.27
192.2	1.40
194.1	1.45
201.4	1.48
201.4	1.59
203.2	1.59
209.1	1.64
209.7	1.85
211.7	1.77
217.3	1.77
217.3	1.90
224.9	1.90
226.1	1.95
232.5	2.03
235.7	2.07
241.7	1.97
242.9	2.11
245.2	2.08
248.5	2.07
252.9	2.32
253.9	2.13
256.0	2.22
262.1	2.36
264.4	2.32
264.4	2.40
271.6	2.40
272.3	2.31
274.2	2.52
279.8	2.47
282.2	2.58
CURVE 16 (cont.)‡	
286.2	2.56
291.1	2.60
294.2	2.60
301.8	2.75
303.0	2.73*
309.4	2.90*
311.0	2.76*
316.9	2.97*
319.5	2.81*
320.4	2.94*
322.4	2.88*
324.6	2.88*
329.7	3.04*
331.8	3.01*
339.5	3.06*
CURVE 22‡	
81	-0.58
88	-0.37
95	-0.47
105	-0.40
114	-0.49
119	-0.17
131	0.10
147	0.34
165	1.05
180	1.14
184	1.34
194	1.34
201	1.68
206	1.55
218	1.88
225	2.04
237	2.06
257	2.26
272	2.38
277	2.44
293	2.60*
301	2.62*
322	2.83*
343	2.92*
CURVE 23‡	
91	-0.58
103	-0.54
125	-0.17
128	-0.28
128	0.00
131	-0.15
152	0.50
170	0.88
188	1.42
206	1.73
282	2.49
293	2.60
295	2.62
315	2.81*
CURVE 27*	
50	-0.38
60	-0.54
70	-0.60
80	-0.56
90	-0.44
100	-0.28
120	-0.12
140	-0.48
160	-0.63
CURVE 29*,‡	
20	0.00
30	-0.05
40	-0.15
57	-0.32
65	-0.43
75	-0.45
85	-0.46
95	-0.41
105	-0.24
115	-0.10
125	0.00
135	0.26
199	1.38
207	1.56
283	2.35

*Not shown in figure.

‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 32. THERMAL LINEAR EXPANSION OF SULFUR S

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	521	Looman, C.M. and Tuinstra, F.	1969	X	112-351	S-psi fibrous	Fibrous specimen; lattice parameter expansion measured along a-axis; lattice parameter reported at 293 K is 8.092 Å.
2*	521	Looman, C.M. and Tuinstra, F.	1969	X	110-352	S-psi fibrous	The above specimen; expansion measured along b-axis; lattice parameter reported at 293 K is 9.200 Å.

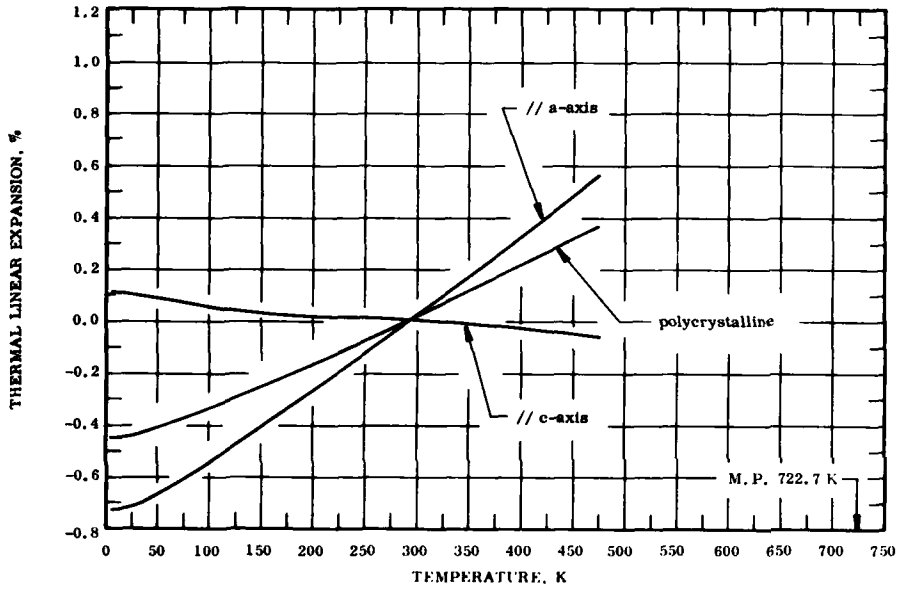
DATA TABLE 32. THERMAL LINEAR EXPANSION OF SULFUR S

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
112	-1.804
149	-1.149
301	0.173
351	0.445
CURVE 2*	
110	-1.370
149	-0.967
352	0.391

*No figure given.

FIGURE AND TABLE NO. 33R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF TELLURIUM Te



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
2	0.111	-0.736	-0.454	0.007
3	0.111	-0.736	-0.454	0.026
4	0.111	-0.736	-0.454	0.06
5	0.111	-0.736	-0.454	0.12
6	0.111	-0.736	-0.454	0.20
7	0.111	-0.736	-0.454	0.33
8	0.111	-0.736	-0.454	0.53
10	0.110	-0.735	-0.453	1.0
12	0.110	-0.734	-0.453	1.8
14	0.109	-0.733	-0.452	2.6
16	0.108	-0.732	-0.452	3.5
18	0.107	-0.730	-0.451	4.5
20	0.106	-0.728	-0.450	5.3
22	0.104	-0.726	-0.449	6.3
24	0.103	-0.723	-0.448	7.2
26	0.101	-0.720	-0.446	8.0
28	0.099	-0.716	-0.444	8.7
30	0.097	-0.713	-0.443	9.4
35	0.093	-0.703	-0.438	11.0
40	0.089	-0.692	-0.432	12.4
45	0.084	-0.680	-0.425	13.1
50	0.080	-0.668	-0.419	14.0
60	0.073	-0.643	-0.404	14.9
80	0.061	-0.591	-0.374	15.9
100	0.052	-0.538	-0.341	16.4
150	0.035	-0.403	-0.257	17.1
200	0.021	-0.266	-0.170	17.7
250	0.009	-0.125	-0.080	18.4
293	0.000	0.000	0.000	18.8
350	-0.012	0.170	0.109	19.3
400	-0.025	0.322	0.206	19.8
450	-0.042	0.480	0.306	20.1
475	-0.052	0.560	0.356	20.2

REMARKS

The recommended values for the axial thermal expansion are based on the data for single crystals. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ±3% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = 0.105 - 6.685 \times 10^{-4} T + 1.638 \times 10^{-6} T^2 - 1.950 \times 10^{-9} T^3$ (100-475 K)

// a-axis: $\Delta L/L_0 = -0.799 + 2.574 \times 10^{-3} T + 3.946 \times 10^{-7} T^2 + 4.484 \times 10^{-10} T^3$ (100-475 K)

polycrystalline: $\Delta L/L_0 = -0.497 + 1.479 \times 10^{-3} T + 8.643 \times 10^{-7} T^2 - 4.127 \times 10^{-10} T^3$ (100-475 K)

The tabulated values for the coefficient of thermal expansion are derived from the experimental data and are considered accurate to about ±5%.

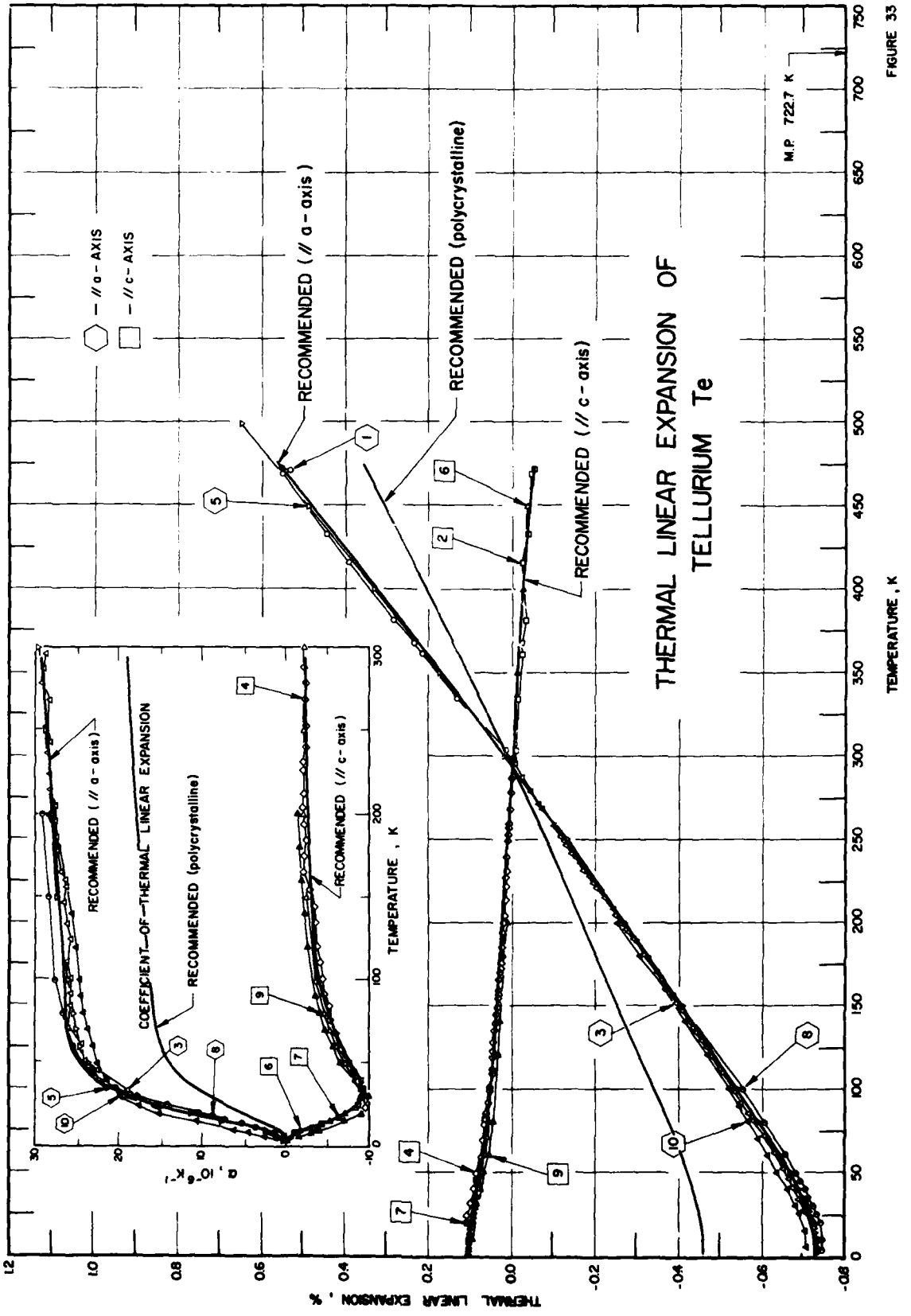

THERMAL LINEAR EXPANSION OF TELLURIUM Te
M.P. 722.7 K
RECOMMENDED (// a - axis)
RECOMMENDED (polycrystalline)
RECOMMENDED (// c - axis)
// a - AXIS
// c - AXIS
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶K⁻¹

FIGURE 33

SPECIFICATION TABLE 33. THERMAL LINEAR EXPANSION OF TELLURIUM Te

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	522	Deshpande, V.T. and Pawar, R.	1965	X	298-474		Specimen rods of tellurium obtained from Johnson Matthey; filed to obtain fine specimen powder, portions of powder annealed at temperatures between 250-300 C in open or evacuated pyrex tubes for 12 hr; reflections recorded with CuKα radiation measured from (216), (323), (315), (306), and (207) planes; lattice parameter expansion measured along a-axis reported at 298.2 K is 4.4566 Å; 4.4562 Å at 293.2 K determined by graphical extrapolation.
2	522	Deshpande, V.T. and Pawar, R.	1965	X	298-474		The above specimen except lattice parameter measured along c-axis; reported at 298.2 K is 5.9264 Å; 5.9266 Å at 293.2 K determined by graphical extrapolation.
3	523	Novikova, S.I.	1969	L	20-300		Single crystal specimen having carrier concentration of $\sim 10^{16}$ cm^{-3}; expansion measured perpendicular to c-axis in six separate runs; data compilation of all six runs.
4	523	Novikova, S.I.	1969	L	20-300		The above specimen; expansion measured parallel to c-axis.
5	524	Ibach, H. and Ruin, R.	1970	E/I	2-500		Crystal specimen; 3995-4065 μm long, 4 mm thick; obtained from Physikalisches Institut der Universität Köln; impurity contamination 10^{15} cm^{-3}; 4 sets of specimens, 2 annealed in argon at 573 K for 50 hr, cooled down slowly in 24 hr; average of 2 runs of 3 different sets of specimens; expansion measured perpendicular to c-axis; reported error 3%.
6	524	Ibach, H. and Ruin, R.	1970	E/I	2-450		Similar to the above specimen; 3965-4035 μm long, 6 mm thick; expansion measured along c-axis; reported error 4%.
7	466	Hortal, H. and Leadbetter, A.J.	1972	E	45-200		Single crystal specimen of purity 4 N obtained from Metals Research Ltd. in form of hexagonal prism, 30 mm long, 17 mm diameter; c-axis parallel to specimen axis; low temperature accuracy 5%, higher temperature 3% for coefficient of thermal linear expansion parallel to c-axis.
8	466	Hortal, H. and Leadbetter, A.J.	1972	E	45-200		The above specimen; expansion measured parallel to a-axis.
9	487	Ahmed, S. and Weintraub, S.	1972	E	6-200		Four single crystal specimens of orientation $\Psi = 0°$, 45.5°, 86.5°, 90°, the $\Psi = 0°$ crystals obtained from Wacker Chemie Co., other orientation grown by authors from 5 N purity material from Messrs. Koch-Light Ltd.; all crystals 5 cm long; expansion measured parallel to c-axis.
10	487	Ahmed, S. and Weintraub, S.	1972	E	6-200		The above specimen; expansion measured parallel to a-axis.
11*	493	White, G.K.	1973	E	4-30		Crystal specimen of 6 N purity from Wacker-Chemitronic (W. Germany); initial 80 mm long oriented parallel to c-axis.
12*	493	White, G.K.	1973	E	4-30		The above specimen; expansion measured parallel to a-axis.

* Not shown in figure.

DATA TABLE 33. THERMAL LINEAR EXPANSION OF TELLURIUM Te

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
298	0.0089
303	0.0179
334	0.1301
361	0.2154
367	0.2333
382	0.2827
416	0.3949
433	0.4443
469	0.5497
472	0.5318
474	0.5520

CURVE 2

T	$\Delta L/L_0$
298	-0.0033
303	-0.0067
334	-0.0168
361	-0.0253
367	-0.0219
382	-0.0337
416	-0.0236
433	-0.0371
469	-0.0455
472	-0.0556
474	-0.0539

CURVE 3‡

T	$\Delta L/L_0$
25.6	-0.706
27.8	-0.702
34.1	-0.691
42.7	-0.674
46.5	-0.666
52.5	-0.652
62.5	-0.627
72.0	-0.603
81.6	-0.578
82.7	-0.575*
85.9	-0.567
86.4	-0.566*
93.2	-0.548
98.9	-0.534
99.5	-0.532*
102.3	-0.525
103.1	-0.523*
110.8	-0.503
112.3	-0.499

CURVE 3 (cont.)‡

T	$\Delta L/L_0$
120.4	-0.478
125.3	-0.466
129.4	-0.455
134.8	-0.441
137.3	-0.434
140.2	-0.427
147.1	-0.409
152.9	-0.393
156.3	-0.384
157.4	-0.381*
165.2	-0.360
169.0	-0.350
178.4	-0.324
181.2	-0.317
187.5	-0.300
190.3	-0.292
194.5	-0.280
196.9	-0.274
205.7	-0.249
208.4	-0.242*
208.4	-0.242
215.8	-0.242
222.8	-0.201
224.7	-0.196
228.5	-0.185
233.9	-0.170
236.4	-0.162
238.4	-0.157
243.6	-0.142
247.8	-0.130
249.1	-0.127
252.8	-0.116
253.4	-0.114*
258.4	-0.100
268.3	-0.072
271.8	-0.062
278.4	-0.043
287.1	-0.018*
287.1	-0.018
296.5	0.009

CURVE 4‡

T	$\Delta L/L_0$
24.2	0.107
31.1	0.100
40.6	0.092
49.1	0.084

CURVE 4 (cont.)‡

T	$\Delta L/L_0$
58.5	0.077
68.6	0.071
77.1	0.066
81.6	0.064
83.3	0.063
85.9	0.062
92.1	0.059
99.3	0.056
101.2	0.055
109.4	0.051
112.3	0.050
118.4	0.047
123.2	0.046
127.2	0.044
135.9	0.041
139.3	0.040
145.0	0.038
149.1	0.037
149.0	0.037*
155.2	0.035
157.8	0.034
159.4	0.034
166.6	0.032
169.9	0.065
173.9	0.027
175.9	0.026
185.2	0.024
185.2	0.024*
193.1	0.022
194.9	0.022*
200.8	0.021
204.2	0.020
213.8	0.018
222.4	0.016
227.1	0.015
231.7	0.014
239.0	0.013
240.5	0.012*
249.8	0.010
253.2	0.009
257.1	0.008
259.6	0.008
269.2	0.006
278.8	0.003
287.9	0.001

CURVE 5‡

T	$\Delta L/L_0$
2	-0.731
3	-0.731*
4	-0.731
7	-0.731*
6	-0.731
7	-0.731*
8	-0.731
9	-0.731*
10	-0.731
12	-0.730
14	-0.729
16	-0.728
18	-0.726
20	-0.724
22	-0.721
24	-0.718
26	-0.715
28	-0.712
30	-0.708
32	-0.704
35	-0.698
40	-0.687
50	-0.664
60	-0.640
70	-0.615
80	-0.590
100	-0.539
150	-0.406
200	-0.268
250	-0.126
300	0.020
350	0.171
400	0.326
450	0.484
500	0.645

CURVE 6‡

T	$\Delta L/L_0$
2	0.103
3	0.103*
4	0.103
7	0.103*
6	0.103
7	0.103*
8	0.103
9	0.102*
10	0.102

CURVE 6 (cont.)‡

T	$\Delta L/L_0$
12	0.102
14	0.101
16	0.100
18	0.099
20	0.098
22	0.096
24	0.095
26	0.093
28	0.091
30	0.089
32	0.088
35	0.085
40	0.080
50	0.073
60	0.066
70	0.060
80	0.055
100	0.047
150	0.032
200	0.021*
250	0.010*
300	-0.002*
350	-0.013
400	-0.026
450	-0.039

CURVE 7‡

T	$\Delta L/L_0$
4.5	0.108*
5	0.108*
6	0.108*
7	0.108*
8	0.108*
9	0.108*
10	0.108*
12	0.108*
14	0.107*
16	0.106*
18	0.105*
20	0.103
25	0.099*
30	0.095*
35	0.090*
40	0.086*
45	0.081
50	0.077*
60	0.070*

CURVE 7 (cont.)‡

T	$\Delta L/L_0$
80	0.059*
100	0.050*
150	0.034*
200	0.022*

CURVE 8‡

T	$\Delta L/L_0$
4.5	-0.749
5	-0.749*
6	-0.749*
7	-0.749*
8	-0.748*
9	-0.748*
10	-0.748
12	-0.748*
14	-0.747*
16	-0.745*
18	-0.744*
20	-0.742
25	-0.736
30	-0.728
35	-0.718
40	-0.708
45	-0.696
50	-0.684
60	-0.659
80	-0.607
100	-0.553
150	-0.413*
200	-0.268

CURVE 9‡

T	$\Delta L/L_0$
6	0.099*
8	0.099*
10	0.098
15	0.095*
20	0.091*
25	0.087*
30	0.082*
40	0.072
50	0.064
60	0.058
70	0.053*
80	0.048
90	0.044*
100	0.041*

* Not shown in figure.

‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 33. THERMAL LINEAR EXPANSION OF TELLURIUM Te (continued)

T	$\Delta L/L_0$
CURVE 9 (cont.)‡	
120	0.035
140	0.029
160	0.025*
180	0.021
200	0.017
CURVE 10‡	
6	-0.711
8	-0.710*
10	-0.709*
15	-0.705
20	-0.699*
25	-0.691
30	-0.681
40	-0.661
50	-0.639
60	-0.616
70	-0.593
80	-0.569
90	-0.545
100	-0.520
120	-0.470
140	-0.419
160	-0.367
180	-0.313
200	-0.258
CURVE 11*,‡	
4.0	0.111
6.2	0.111
6.8	0.110
7.2	0.110
7.9	0.110
8.6	0.110
9.3	0.110
10.0	0.110
10.8	0.110
11.8	0.109
13.0	0.109
14.2	0.108
15.3	0.108
16.8	0.107
18.3	0.106
18.3	0.106
19.7	0.105
21.3	0.104
22.7	0.103

T	$\Delta L/L_0$
CURVE 11 (cont.)*,‡	
24.4	0.102
25.9	0.101
27.3	0.099
28.7	0.098
29.7	0.097
CURVE 12*,‡	
4.0	-0.733
5.8	-0.733
6.4	-0.733
6.9	-0.733
7.3	-0.733
7.9	-0.733
8.3	-0.732
9.0	-0.732
9.8	-0.732
10.7	-0.732
11.7	-0.732
12.9	-0.731
14.3	-0.730
15.4	-0.730
16.7	-0.729
18.3	-0.727
19.7	-0.726
21.0	-0.724
22.6	-0.722
24.3	-0.720
26.0	-0.717
27.3	-0.715
28.6	-0.713
29.8	-0.710

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 33. COEFFICIENT OF THERMAL LINEAR EXPANSION OF TELLURIUM Te

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3‡	
25.6	15.88
27.8	17.13*
34.1	18.82
42.7	20.54*
46.5	22.51
52.5	24.07
62.5	24.59
72.0	26.08
81.6	26.36*
82.7	25.77*
85.9	25.98
86.4	25.70*
93.2	25.91
98.9	25.21*
99.5	25.93*
102.3	25.44*
103.1	25.79
110.8	25.69*
112.3	26.21
120.4	25.45*
125.3	25.96
129.4	25.92*
134.8	26.18
137.3	26.31*
140.2	26.14*
147.1	26.66
152.9	26.52*
156.3	26.36
157.4	26.80*
165.2	26.96
169.0	26.92*
178.4	27.36
181.2	27.10*
187.5	27.52
190.3	27.60*
194.5	27.65*
196.9	27.65
205.7	27.65
208.4	27.94*
208.4	28.32*
215.8	28.32
222.8	28.41*
224.7	28.21
228.5	28.26*
233.9	28.63*

T	α
CURVE 3 (cont.)‡	
236.4	28.50
238.4	28.29*
243.6	28.15
247.8	28.14*
249.1	28.79*
252.8	28.29*
253.4	28.84
258.4	28.32*
268.3	28.26
271.8	28.51*
278.4	29.31
287.1	29.09
287.1	28.80*
296.5	28.75
CURVE 4‡	
24.2	-9.65
31.1	-9.12
40.6	-8.76
49.1	-8.28*
58.5	-6.74
68.6	-6.09
77.1	-5.10
81.6	-4.66*
83.3	-4.77*
85.9	-5.06
92.1	-4.65
99.3	-4.33*
101.2	-4.48
109.4	-4.28*
112.3	-4.18
118.4	-3.86*
123.2	-3.81
127.2	-3.77*
135.9	-3.42
139.3	-3.46*
145.0	-3.37
149.1	-3.15*
149.0	-2.95*
155.2	-2.95
157.8	-2.52*
159.4	-2.14*
166.6	-2.13
169.9	-2.31*

T	α
CURVE 4 (cont.)‡	
173.9	-2.61*
175.9	-2.14
185.2	-2.47
185.2	-2.33*
193.1	-2.33*
194.9	-2.19
200.8	-1.92*
204.2	-2.09
213.8	-2.21
222.4	-2.06*
227.1	-2.11
231.7	-2.07
239.0	-2.07*
240.5	-2.31
249.8	-2.45*
253.2	-2.30
257.1	-2.14*
259.6	-2.43*
269.2	-2.32
278.8	-2.34
287.9	-2.28
CURVE 5‡	
2	0.027*
3	0.086*
4	0.188
7	0.340*
6	0.554*
7	0.849*
8	1.267*
9	1.800*
10	2.480
12	4.050*
14	5.830*
16	7.700
18	9.560*
20	11.340
22	13.800*
24	15.000
26	16.500*
28	17.900*
30	19.100
32	20.100*
35	21.100

T	α
CURVE 5 (cont.)‡	
40	22.200
50	23.600
60	24.500
70	25.000
80	25.400
100	26.000
150	27.200
200	28.000
250	28.800
300	29.700
350	30.600*
400	31.300*
450	31.900*
500	32.400*
CURVE 6‡	
2	-0.026*
3	-0.068*
4	-0.148
7	-0.274*
6	-0.454*
7	-0.693*
8	-0.998*
9	-1.370*
10	-1.810
12	-2.860*
14	-3.910*
16	-5.140
18	-6.160*
20	-7.040
22	-7.810*
24	-8.300
26	-8.690*
28	-8.920*
30	-9.080
32	-9.150*
35	-9.060
40	-8.550
50	-7.120
60	-6.030
70	-5.270
80	-4.660
100	-3.660
150	-2.400

T	α
CURVE 6 (cont.)‡	
200	-2.180
250	-2.180
300	-2.290
350	-2.420*
400	-2.550*
450	-2.690*
CURVE 7‡	
4.5	-0.12*
5	-0.21*
6	-0.41*
7	-0.71*
8	-1.05
9	-1.47*
10	-1.95*
12	-3.05
14	-4.25
16	-5.40*
18	-6.37
20	-7.25*
25	-8.70
30	-9.25*
35	-9.30
40	-9.00
45	-8.30
50	-7.70
60	-6.50*
80	-4.95*
100	-3.90
150	-2.60*
200	-2.10*
CURVE 8‡	
4.5	0.15*
5	0.22*
6	0.44*
7	0.74*
8	1.15
9	1.70*
10	2.32*
12	3.70
14	5.30
16	7.10

T	α
CURVE 8 (cont.)‡	
18	8.80
20	10.4
25	14.2
30	17.8
35	20.2
40	22.2
45	23.4
50	24.2
60	25.6
80	26.7
100	27.6
150	28.5
200	29.2
CURVE 9‡	
6	1.75
8	-3.00
10	-4.00
15	-7.00
20	-9.00
25	-9.50*
30	-10.00
40	-9.00*
50	-6.50
60	-5.80
70	-4.90
80	-4.30
90	-3.70
100	-3.50*
120	-2.70
140	-2.50
160	-2.00
180	-1.90
200	-1.80
CURVE 10‡	
6	2.50
8	4.50
10	6.07
15	10.08
20	15.12
25	17.63
30	19.64

*Not shown in figure.

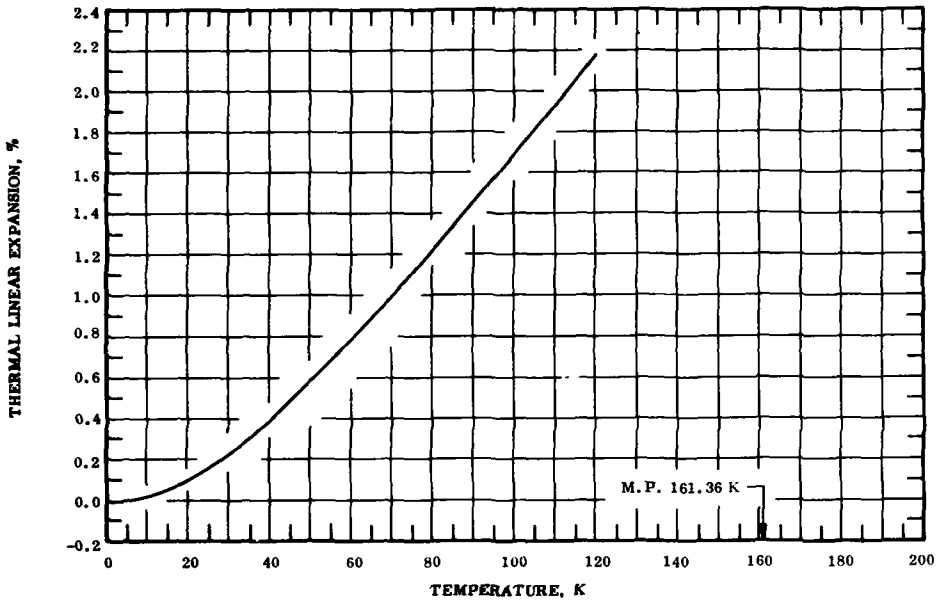
‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 33. COEFFICIENT OF THERMAL LINEAR EXPANSION OF TELLURIUM Te (continued)

T	α
CURVE 10 (cont.)‡	
40	21.25
50	22.25
60	23.00
70	23.75
80	24.25
90	24.50
100	24.75
120	25.25
140	25.75
160	26.35
180	27.25
200	28.20
CURVE 11‡	
4.0	-0.4
6.2	-0.7
6.8	-0.7
7.2	-0.9
7.9	-1.0
8.6	-1.3
9.3	-1.6
10.0	-2.0
10.8	-2.4
11.8	-3.0
13.0	-3.7
14.2	-4.3
15.3	-5.0
16.8	-5.7
18.3	-6.4
19.7	-7.0
21.3	-7.7
22.7	-8.0
24.4	-8.5
25.9	-8.8
27.3	-9.0
28.7	-9.1
29.7	-9.2
CURVE 12‡	
4.0	0.1
5.8	0.3
6.4	0.5
6.9	0.6
7.3	0.8
7.9	1.0
8.3	1.4
9.0	1.8
9.8	2.3
10.7	3.0
11.7	3.8
12.9	4.9
14.3	6.0
15.4	7.1
16.7	8.4
18.3	9.9
19.7	11.1
21.0	12.5
22.6	13.7
24.3	14.9
26.0	16.1
27.3	17.0
28.6	17.8
29.8	18.4

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 34R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF XENON Xe



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$ [§]	α
0	-0.0040	
4	0.0000	10
5	0.0019	15
10	0.020	52
15	0.054	95
20	0.100	122
30	0.228	155
40	0.393	181
50	0.580	195
60	0.797	210
70	1.015	218
80	1.230	228
90	1.433	240
100	1.680	253
110	1.930	
120	2.180	

[§] This curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.

REMARKS

The recommended values are considered accurate to within ±5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.001 - 1.094 \times 10^{-3} T + 3.414 \times 10^{-4} T^2 - 1.691 \times 10^{-6} T^3 \quad (4\text{-}90\ K)$$

The tabulated values for the coefficient of thermal expansion are derived from the experimental data (Curves 6 and 7) and are considered accurate to about ±5%.

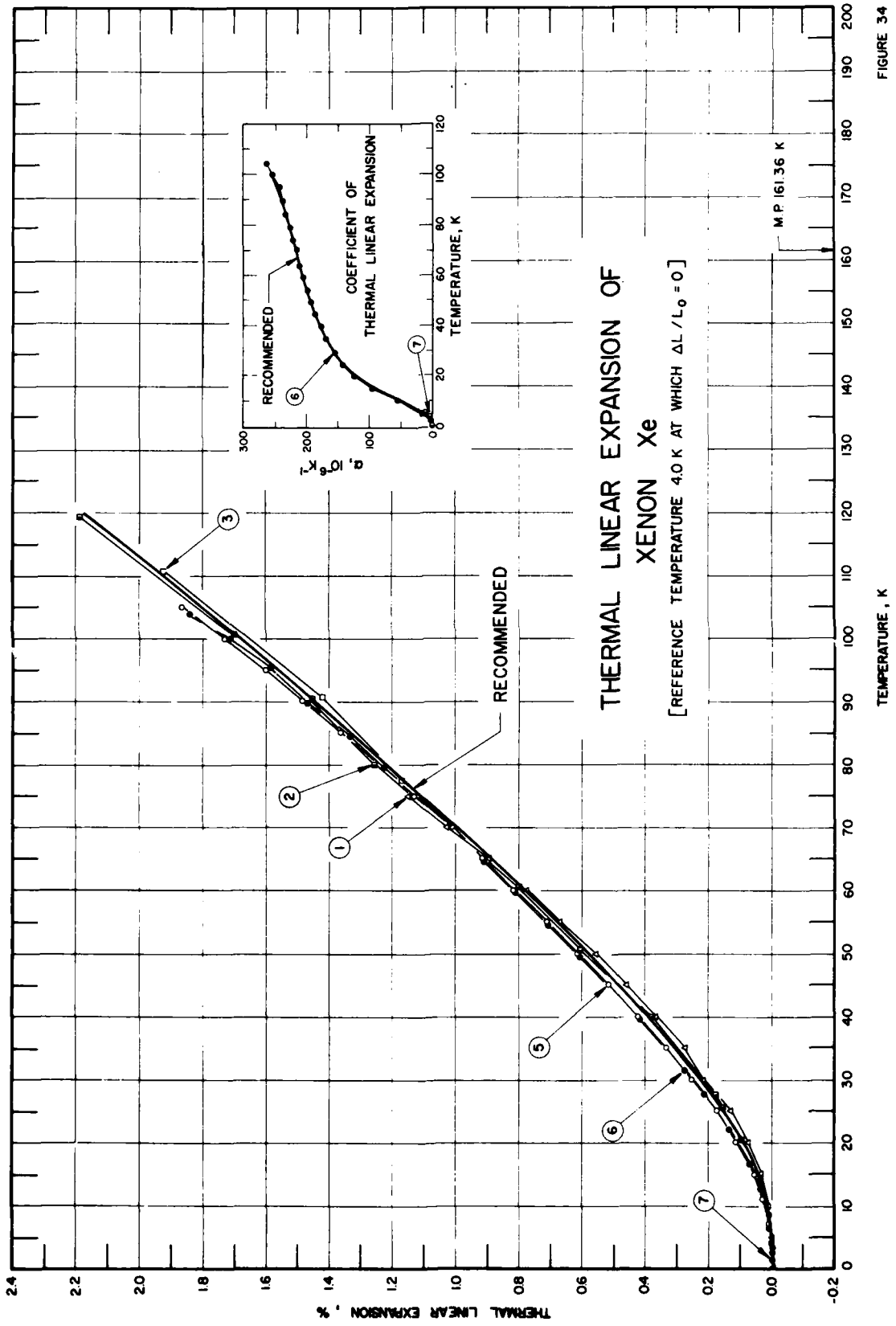

THERMAL LINEAR EXPANSION OF
XENON Xe
[REFERENCE TEMPERATURE 4.0 K AT WHICH ΔL / L0 = 0]
M.P. 161.36 K
RECOMMENDED
COEFFICIENT OF
THERMAL LINEAR EXPANSION
RECOMMENDED
TEMPERATURE, K
α, 10⁻⁶ K⁻¹
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K

FIGURE 34

SPECIFICATION TABLE 34. THERMAL LINEAR EXPANSION OF XENON Xe

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	525	Sears, D. R. and Klug, H. P.	1962	X	0-75		< 0.005 Kr, < 0.003 total N_2, O_2, Ar, H_2 and hydrocarbons; flat-specimen counter diffratometry, Ni-filtered CuKα radiation used; specimen injected into the vacuum space of the cryostat and impinged upon a gold-plated OFHC copper surface; typical specimen thicknesses 0.0035 and 0.0075 in.; smoothed values of lattice parameter recorded; lattice parameter reported at 0 K is 6.1317 Å; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
2	526	Eatwell, A. J. and Smith, B. L.	1961	X	20-120		Polycrystalline, deposited from the vapor in a Perspex tube of 1 mm internal diameter; stated by the British Oxygen Co., Ltd. to be of 99-100% purity, remainder being krypton; temperature constant within 0.04 K at 20 K and to 0.01 K at 90 K; accurate to ±0.001 Å; Debye-Scherrer photographic technique used; lattice parameter reported at 20.3 K is 6.1383 Å; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
3	526	Eatwell, A. J. and Smith, B. L.	1961	D	77-110		Similar to the above specimen; lattice parameters estimated from the bulk density measurements, accurate to within ± 0.005 Å; lattice parameter reported at 77.5 K is 6.2041 Å; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
4*	491	Cheesman, G. H. and Soane, C. M.	1957	X	58-88.9		Commercial 99-100 purity, principal impurity Kr, measurement of lattice constant referred to Cu at 293 K; lattice constant reported at 58 K is 6.185 kX; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
5	492	Tilford, C. R. and Swenson, C. A.	1972	L	0-105		Specimen 0.375 in. diameter, 30 mm long; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
6	492	Tilford, C. R. and Swenson, C. A.	1972	L	25-105	Set I	Similar to the above specimen; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
7	492	Tilford, C. R. and Swenson, C. A.	1972	L	1.5-5.8	Set II	Similar to the above specimen; capacitance-cell gap made smaller for second set by heating cell to a temperature greater than initial assembly temperature; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

DATA TABLE 34. THERMAL LINEAR EXPANSION OF XENON Xe

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1[§]	
0	-0.0016
5	0.0000
10	0.0114
15	0.0359
20	0.0750
25	0.1288
30	0.2136
35	0.2772
40	0.3653
45	0.4583
50	0.5577
55	0.6670
60	0.7795
65	0.8986
70	1.0225
75	1.1497
CURVE 2[§]	
20.3	0.0913
25.6	0.1516
26.6	0.1631
27.9	0.1794
30.2	0.2136*
40.0	0.3799
50.7	0.6001
60.5	0.7990
70.2	1.0256*
80.1	1.2556
90.3	1.4578
100.9	1.7056
119.9	2.1948
CURVE 3[§]	
77.5	1.1643
90.8	1.4219
110.7	1.9257
CURVE 4*[,§]	
58	0.961
77.4	1.303
88.9	1.466

T	$\Delta L/L_0$
CURVE 5[§]	
1	-0.00039*
1.5	-0.00039*
2	-0.00037*
2.5	-0.00034*
3	-0.00028*
3.5	-0.00017*
4	0.00000
4.5	0.00026*
5	0.00064*
5.5	0.0012*
6	0.0018*
6.5	0.0027*
7	0.0038
7.5	0.0051*
8	0.0066*
8.5	0.0084*
9	0.0104*
9.5	0.0126*
10	0.0151*
10.5	0.0179*
11	0.0209
12	0.0276*
13	0.0351*
14	0.0435*
15	0.0526
16	0.0625*
18	0.0842*
20	0.1081
25	0.1757
30	0.2516
35	0.3337
40	0.4209
45	0.5126
50	0.6076
55	0.7056
60	0.8076
65	0.9116
70	1.020
75	1.131
80	1.245*
85	1.361
90	1.481
95	1.605
100	1.732
105	1.863

T	$\Delta L/L_0$
CURVE 6[‡,§]	
2.520	-0.00035*
2.769	-0.00032
3.044	-0.00018*
3.352	-0.00022*
3.695	-0.00013*
4.063	0.000015*
4.437	0.00021*
4.846	0.00050*
5.335	0.00095*
5.868	0.0016*
6.498	0.0027
7.200	0.0043*
7.850	0.0061*
8.644	0.0089
9.593	0.0131*
10.528	0.0180*
11.554	0.0245*
12.709	0.0328
13.823	0.0419*
15.043	0.0530*
16.563	0.0684
18.221	0.0867*
20.035	0.1086*
22.058	0.1347
24.268	0.1652*
27.716	0.2156
29.227	0.2387*
31.475	0.2745
34.969	0.3323*
39.956	0.4188
44.958	0.5096*
49.965	0.6042
54.973	0.7020
59.987	0.8031
64.979	0.9070
70.271	1.0203
74.984	1.1236
79.318	1.2204
84.328	1.3353
89.997	1.4693
95.043	1.5907
100.052	1.7152
104.935	1.8410

T	$\Delta L/L_0$
CURVE 7[‡,§]	
1.539	-0.00038
1.763	-0.00038*
2.024	-0.00037*
1.487	-0.00038*
1.705	-0.00038*
1.935	-0.00037*
2.150	-0.00036*
2.375	-0.00035*
2.623	-0.00033*
2.886	-0.00029*
3.145	-0.00025
3.426	-0.00019*
3.770	-0.000088*
3.008	-0.00028*
3.311	-0.00022*
3.615	-0.00014*
3.943	-0.000027*
4.341	0.00016*
4.769	0.00044*
5.298	0.00092*
5.880	0.0016*

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.
§ This curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 34. COEFFICIENT OF THERMAL LINEAR EXPANSION OF XENON Xe

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 6‡	
2.520	0.911
2.769	1.233*
3.044	1.663*
3.352	2.322*
3.695	3.236*
4.063	4.467*
4.437	5.98*
4.846	7.96*
5.335	10.79
5.868	14.43*
6.498	19.33*
7.200	25.42*
7.850	31.39*
8.644	39.23*
9.593	48.50*
10.528	57.7
11.554	67.3*
12.709	77.4*
13.823	86.5*
15.043	95.6
16.563	105.9*
18.221	115.8*
20.035	125.0
22.058	133.7*
24.268	142.5
27.716	149.3*
29.227	156.6
31.475	161.9*
34.969	169.1
39.956	177.8
44.958	185.4
49.965	192.1
54.973	198.6
59.987	204.9
64.979	211.1
70.271	217.1
74.984	221.5
79.318	225.0
84.328	233.9
89.997	238.7
95.043	242.6
100.052	254.2
104.935	261.1

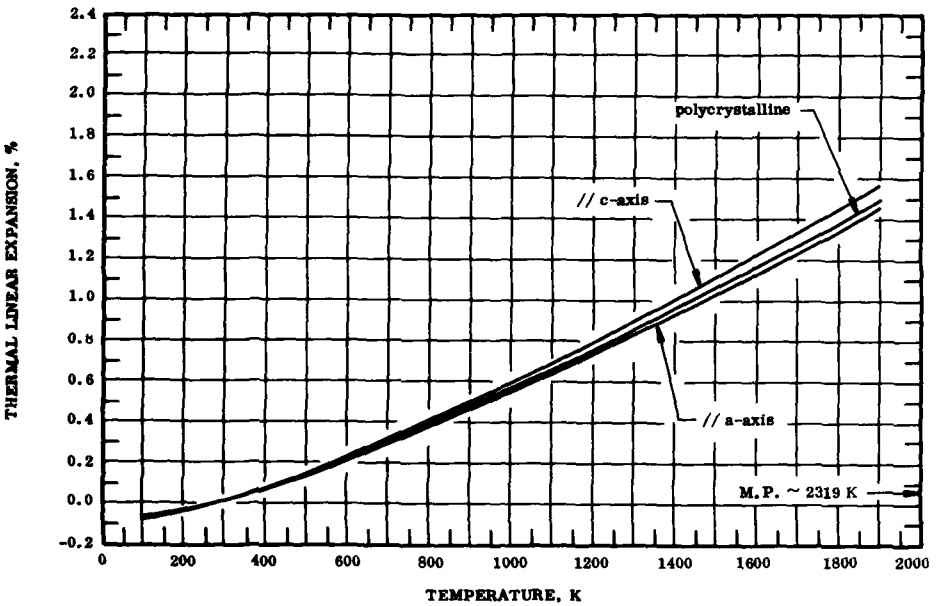
T	α
CURVE 7*, ‡	
1.539	0.188
1.763	0.291
2.024	0.445
1.487	0.189
1.705	0.264
1.935	0.384
2.150	0.549
2.375	0.744
2.623	1.025
2.886	1.398
3.145	1.869
3.426	2.497
3.770	3.451
3.008	1.644
3.311	2.255
3.615	3.019
3.943	4.033
4.341	5.55
4.769	7.56
5.298	10.57
5.880	14.50

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L / L_0$.

2. SIMPLE OXIDES

FIGURE AND TABLE NO. 35R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, $10^{-6}\ K^{-1}$]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
100	-0.078	-0.060	-0.066	0.6
150	-0.060	-0.047	-0.051	1.9
200	-0.040	-0.037	-0.038	3.3
250	-0.020	-0.022	-0.021	4.5
293	0.000	0.000	0.000	5.4
400	0.078	0.073	0.075	7.1
500	0.155	0.145	0.148	7.5
600	0.236	0.220	0.225	7.9
700	0.320	0.300	0.305	8.2
800	0.408	0.380	0.388	8.5
900	0.500	0.465	0.476	8.8
1000	0.593	0.552	0.565	9.1
1100	0.690	0.644	0.658	9.4
1200	0.790	0.736	0.754	9.6
1300	0.892	0.830	0.852	9.9
1400	0.998	0.928	0.952	10.1
1500	1.105	1.027	1.054	10.3
1600	1.215	1.128	1.158	10.5
1700	1.325	1.230	1.263	10.6
1800	1.440	1.333	1.370	10.9
1900	1.555	1.440	1.480	11.0

REMARKS

The recommended values for the axial thermal expansion are based on the data for pure samples. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ±3% and are represented approximately by the following equation:

// c-axis: $\Delta L/L_0 = -0.115 + 3.772 \times 10^{-4}\ T - 1.999 \times 10^{-7}\ T^2 + 8.416 \times 10^{-10}\ T^3$ (100-293 K)

$\Delta L/L_0 = -0.192 + 5.927 \times 10^{-4}\ T + 2.142 \times 10^{-7}\ T^2 - 2.207 \times 10^{-11}\ T^3$ (293-1900 K)

// a-axis: $\Delta L/L_0 = -0.124 + 1.056 \times 10^{-3}\ T - 5.175 \times 10^{-6}\ T^2 + 1.030 \times 10^{-8}\ T^3$ (100-293 K)

$\Delta L/L_0 = -0.176 + 5.431 \times 10^{-4}\ T + 2.150 \times 10^{-7}\ T^2 - 2.810 \times 10^{-11}\ T^3$ (293-1900 K)

polycrystalline: $\Delta L/L_0 = -0.121 + 8.303 \times 10^{-4}\ T - 3.519 \times 10^{-6}\ T^2 + 7.152 \times 10^{-9}\ T^3$ (100-293 K)

$\Delta L/L_0 = -0.180 + 5.494 \times 10^{-4}\ T + 2.252 \times 10^{-7}\ T^2 - 2.894 \times 10^{-11}\ T^3$ (293-1900 K)

The tabulated values for the coefficient of thermal expansion are derived from the experimental data and are considered accurate to about ±.%.

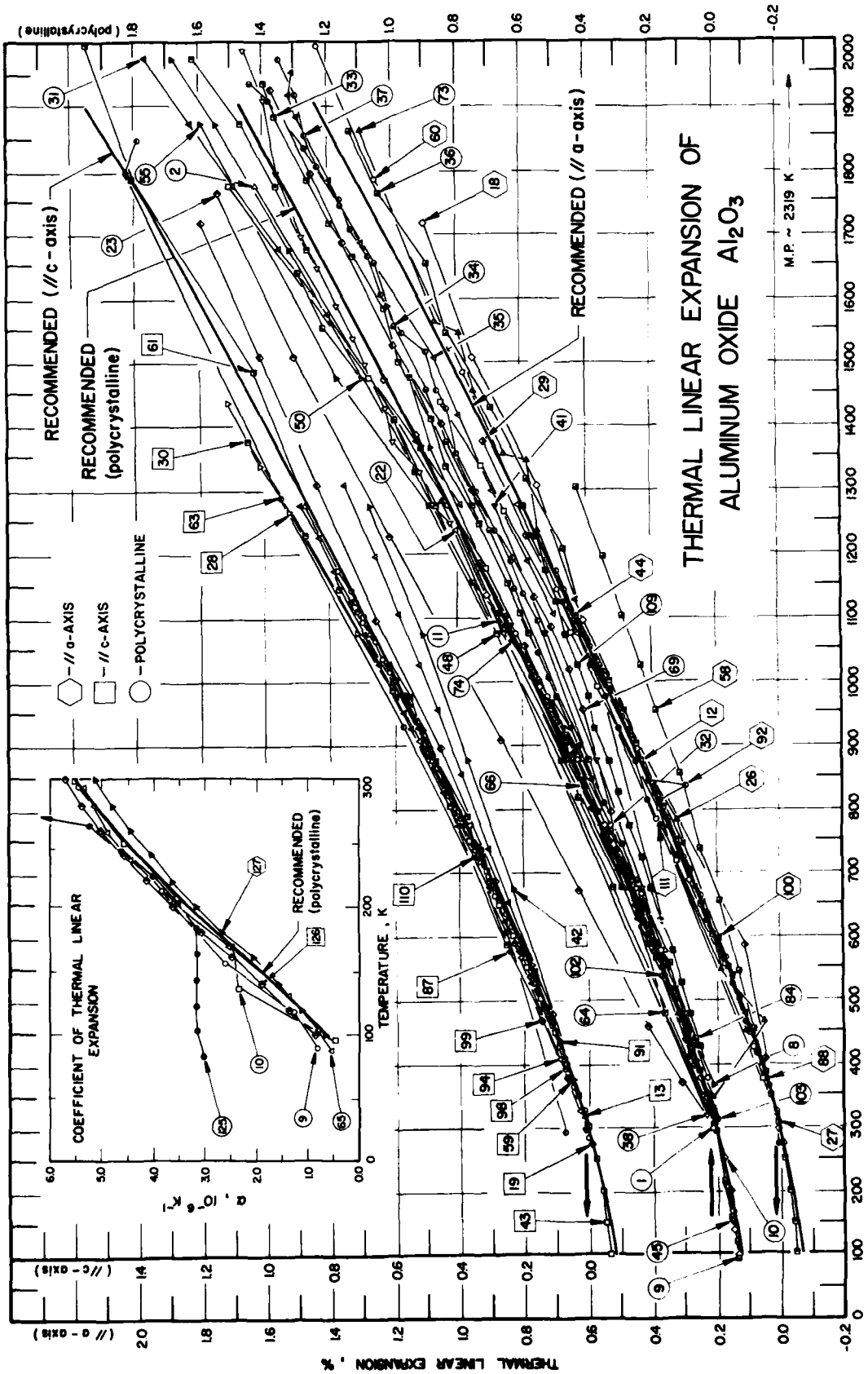

THERMAL LINEAR EXPANSION OF
ALUMINUM OXIDE Al_2O_3
M.P. ~ 2319 K
RECOMMENDED (// c-axis)
RECOMMENDED (polycrystalline)
RECOMMENDED (// a-axis)
– // a-AXIS
– // c-AXIS
– POLYCRYSTALLINE
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED (polycrystalline)
α , 10^{-6} K^{-1}
TEMPERATURE , K
THERMAL LINEAR EXPANSION , %
(// a - axis)
(// c - axis)
(polycrystalline)
TEMPERATURE , K

FIGURE 35

SPECIFICATION TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1	Whittemore, O.J., Jr., and Ault, N.N.	1956	T	298-1773		99 pure; coarse fused grain; rectangular specimen 1.25 x 1.25 x 17.5 cm; ends sawed at rake and to point.
2	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	298-1773		Similar to the above specimen; except sintered; high density.
3*	42	Kirchner, H.P., Merz, K.M., and Smyth, H.T.	1959	L	293-1283	Sapphire	Single crystal rod specimen.
4*	2	Golubev, B.P., Kharitonov, F.Ya., Kalitin, P.P., Vasileva, G.A., and Smirnov, S.N.	1966		373-970		99.4 Al_2O_3, 0.57 MgO, 0.03 Fe_2O_3, trace alkali; heated at 673 K for 16 hr and at 2023 K for 12 hr; pressed and cast.
5*	3	Steele, S.R., Pappis, T., Schilling, H., and Hagen, L.	1967		273, 1273		Specimen deposited from vapor at 1373 K.
6*	4	Kharitonov, F.Ya. and Kalitin, P.P.	1966		293, 973		99.3+ Al_2O_3; 0.5-0.7 MgO, 0.03-0.05 Fe_2O_3; modifying additive MgO added in form $MgCl_2 \cdot 6H_2O$; particles ground to powder, 3.0 rubber added, dried at 363-383 K for 2.5-3 hr, pressed at 500 kg cm^{-3}.
7*	4	Kharitonov, F.Ya. and Kalitin, P.P.	1966		293, 973		Similar to the above specimen; except no rubber added, cast at 338-343 K under 3.5-4.0 atmosphere for 30-40 seconds.
8*	5	Sandmeyer, K.H. and Miller, W.A.	1965		367-1588		99.34 Al_2O_3; 0.39 alkali oxide, 0.13 alkaline oxide, 0.08 SiO_2, 0.06 Fe_2O_3; materials blended in dry state, fused in electric arc furnace, poured into graphite molds, cooled slowly; data from smoothed curve.
9	6	Schauer, A.	1965	I	90-1369		99.995+ pure; cold pressed at 40 000 psi; sintered at 2023 K for 3 hr; density 3.86 g cm^{-3}; reported error ±5%.
10	6	Schauer, A.	1965	I	97-1471		The above specimen; expansion measured with increasing temperature on second test.
11*	6	Schauer, A.	1965	I	1280-474		The above specimen; expansion measured with decreasing temperature.
12	7	Kirchner, H.P., Gruver, R.M., and Walker, R.E.	1966	X	317-1275		Commercial specimen; crushed; expansion measured along a-axis; zero-point correction of 0.003% determined by graphical extrapolation.
13	7	Kirchner, H.P., et al.	1966	X	316-1275		The above specimen; expansion measured along c-axis; zero-point correction of 0.003% determined by graphical extrapolation.
14*	8	Kummer, D.L. and Rosenthal, T.T.	1965	L	256-2139	Norton RA-5058	Specimen obtained from Norton Co.; large porosity size; density 1.36 g cm^{-3}; 0.20-0.25% linear shrinkage; data from smoothed curve.
15*	8	Kummer, D.L. and Rosenthal, T.T.	1965	L	256-2006	Ipsen ICB-3400	Specimen obtained from Ipsen Co.; medium porosity size; density 0.545 g cm^{-3}; specimen began shrinking at about 2000 K; data from smoothed curve.
16*	8	Kummer, D.L. and Rosenthal, T.T.	1965	L	256-1367	MAC LA-2	Specimen density 1.04 g cm^{-3}; specimen began shrinking at 1365 K to 10.8-11.1% linear shrinkage; data from smoothed curve; zero-point correction of -0.012% determined by graphical interpolation.
17*	9	Steery, W.M.	1960		348-968		Commercial specimen; data from smoothed curve.
18	10	Mauer, F.A. and Bolz, L.H.	1957	X	273-1715		99+ Al_2O_3; 0.50 Na_2O, 0.04 Fe_2O_3, 0.025 SiO_2, 0.002 TiO_2; 0.75 loss on ignition; commercial powdered specimen; expansion measured along a-axis in helium atmosphere; zero-point correction of -0.012% determined by graphical interpolation.

*Not shown in figure.

SPECIFICATION TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
19	10	Mauer, F.A. and Bolz, L.H.	1957	X	273-1715		The abpve specimen; expansion measured along c-axis; zero-point correction of -0.012% determined by graphical interpolation.
20*	45	Brett, N.H. and Russell, L.E.	1960	L	348-1273		Specimen of four pieces of sapphire having ends ground to optical flatness; expansion measured at 90° ± 10 to c-axis.
21*	12	Graham, S.A.	1950	T	293-1233		Rectangular specimen, 0.36 x 3.3 cm square; sintered; reported error 5%.
22	12	Graham, S.A.	1950	T	1233-293		The above specimen; expansion measured with decreasing temperature; reported error 5%.
23	56	Gogotsi, G.A., Natsenko, A.I., and Antonenko, V.M.	1969	T	293-1763	Corundum	High purity, 0.1 MgO added.
24*	14	Wilfong, R.L., Domingues, L.P., Furlong, L.R., and Finlayson, T.A.	1963	I	298-1275		Specimen prepared from commercial single-crystal rods; matured overnight at 1273 K, increased to 1473 K for 1 hr and desiccated; heating rate 5 C per min; expansion measured in direction 60° from c-axis; zero-point correction of 0.0029% determined by graphical extrapolation.
25*	14	Wilfong, R.L., et al.	1963	I	298-1274		The above specimen; expansion measured on second test; zero-point correction of 0.0029% determined by graphical extrapolation.
26	15	Klein, D.T.	1958	X	293-2023		Polycrystalline; rectangular specimen 0.25 x 1.5 x 0.125 in.; obtained from Norton Co.; density 3.83 g cm^{-3}; expansion measured along a-axis; author measured both a and c-axis and found no difference in expansion.
27	16	Campbell, W.T. and Grain, C.	1961	X	301-1438	α-alumina	99.8+ Al_2O_3, <0.03 Si, <0.03 Na, <0.02 V, 0.01 Ca, <0.01 each Fe, Zr, Cu, Mg, Mn; specimen obtained from Norton Co.; pressed and fired at 1473 K in oxidizing atmosphere; after cooling, sample ground flat; expansion measured along a-axis with CuKα radiation; reported error <3%; zero-point correction of 0.006% determined by graphical extrapolation.
28	16	Campbell, W.T. and Grain, C.	1961	X	301-1438	α-alumina	The above specimen; expansion measured along c-axis; zero-point correction of 0.004% determined by graphical extrapolation.
29	16	Campbell, W.T. and Grain, C.	1961	X	300-1376	α-alumina	Specimen obtained from Atomics International; average crystal size 17 μ; density 3.83 g cm^{-3}; expansion measured along a-axis; zero-point correction of 0.003% determined by graphical extrapolation.
30	16	Campbell, W.T. and Grain. C.	1961	X	300-1376	α-alumina	The above specimen; expansion measured along c-axis; zero-point correction of 0.005% determined by graphical extrapolation.
31	17	Lukin, E.S. and Poluboyarinov, D.N.	1963	L	293-2073	Body 1	99.7 pure; specimen 4 x 4 x 20 m; prepared from commercial grade G-1 alumina; calcined at 1723 K, ball-milled, HCl washed to remove iron, pressed at 500 kg cm^{-2} and fired at 2003 K; density 3.839 cm^{-3}; apparent porosity 1.7%; heating rate 5-8 C per hr.
32	18	Floyd, J.R.	1964	L	373-1273		Polycrystalline; cylindrical specimen 0.66 cm diameter, 10 cm long; prepared from calcined alumina; wet milled 24 hr with 4.5 kg of 2.5 cm diameter alumina balls in 5.5 qt. alumina mill; dried at 473 K, formed into pressing granules using organic binder; dry pressed, fired at 1923 K for 36 hr, cooled.
33	70	Engberg, C.J. and Zehms, E.H.	1958	T	293-1933	AY-1	Specimen average grain size 17 μ; cold pressed, sintered in oxidizing atmosphere at 2023 K; density 3.83 g cm^{-3}; expansion measured in argon atmosphere.

*Not shown in figure.

SPECIFICATION TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
34	70	Engberg, C.J. and Zehms, E.H.	1958	T	1933-293	AY-1	The above specimen; expansion measured with decreasing temperature; zero-point correction of 0.05%.
35	70	Engberg, C.J. and Zehms, E.H.	1958	T	293-1950	AY-2	Similar to the above specimen; expansion measured with increasing temperature.
36	70	Engberg, C.J. and Zehms, E.H.	1958	T	1865-325	AY-2	The above specimen; expansion measured with decreasing temperature on second test; zero-point correction of 0.21% determined by graphical extrapolation.
37	70	Engberg, C.J. and Zehms, E.H.	1958	T	293-2005	BN-1	Specimen average grain size 17 μ; extruded and sintered in oxidizing atmosphere at 2023 K; density 3.81 g cm^{-3}; expansion measured in argon atmosphere.
38	70	Engberg, C.J. and Zehms, E.H.	1958	T	2105-311	BN-1	The above specimen; expansion measured with decreasing temperature on second test; zero-point correction of 0.78% determined by graphical extrapolation.
39	70	Engberg, C.J. and Zehms, E.H.	1958	T	298-2163	AQ-1	Single crystal specimen; density 3.98 g cm^{-3}; expansion measured in argon atmosphere; zero-point correction of 0.004% determined by graphical extrapolation.
40	70	Engberg, C.J. and Zehms, E.H.	1958	T	2123-298	AQ-1	The above specimen; expansion measured with decreasing temperature; zero-point correction of 0.124% determined by graphical interpolation.
41	13	Gardner, W.J., McClelland, J.D., and Richardson, J.H.	1963	L	473-1273	Linde type B	99.9 pure; cylindrical specimen, 0.66 cm thick, 5.08 cm diameter; fabricated from Linde Type B polishing alumina; hot-pressed under 100 psi with temperature increasing to 1273 K, pressure and temperature increased to 6000 psi and 1773 K, maintained 4 hr, slowly cooled; 99.5% theoretical density; expansion measured in air atmosphere.
42	13	Gardner, W.J., et al.	1963	L	473-1273	Sapphire	Expansion measured along c-axis in air atmosphere.
43	20	Wachtman, J.B., Jr., Scuderi, T.G., and Cleck, G.W.	1962	I	100-1100		0.01-0.1 Si major impurity; single crystal specimen; obtained from Linde Co.; cut from boules of synthetic sapphire; expansion measured parallel to c-axis; zero-point correction of -0.0108% determined by graphical interpolation.
44	20	Wachtman, J.B., Jr., et al.	1962	I	100-1100		The above specimen; expansion measured perpendicular to c-axis; zero-point correction of -0.0095% determined by graphical interpolation.
45	20	Wachtman, J.B., Jr., et al.	1962	I	100-1100		99$^+$ Al_2O_3, <1.0 Mg; polycrystalline specimen; obtained from General Electric Co.; sintered; density 3.974 g cm^{-3}; zero-point correction of -0.116% determined by graphical interpolation.
46*	21	Mullineaux, J.L.	1963	R	293-1473	Morganite alumina	Cylindrical specimen 0.943 cm diameter, 30.5 cm long; obtained from Morganite Inc.; density 3.78 g cm^{-3}.
47*	22	Sklarew, S.	1959		294, 1672	Rokide A	Rod specimen, 0.125-0.188 in. diameter; melted in flame; molten droplets sprayed on working surface, forming coating of laminar flakes; expansion of coating measured.
48	23	Nielsen, T.H. and Leipold, M.H.	1962	L	298-1973	HP102	99.5 pure; specimen 3 in. long; final grain size 17 ± 2.6 μ; hot-pressed in atmosphere 3500 psi, 1723 K for 30 min; expansion measured in air atmosphere; data reported from smoothed curve.
49*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	1773-298	HP102	The above specimen; expansion measured with decreasing temperature.
50	23	Nielsen, T.H. and Leipold, M.H.	1962	L	298-2073	HP102	Similar to the above specimen; grain size 18.5 ± 0.8 μ; expansion measured in air atmosphere.

*Not shown in figure.

SPECIFICATION TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
51*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	1973-298	HP102	The above specimen; expansion measured with decreasing temperature.
52*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	298-2073	HP102	Similar to the above specimen; initial grain size 18.5±0.8 μ, final 20-50 μ.
53*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	1773-298	HP102	The above specimen; expansion measured with decreasing temperature.
54*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	298-2073	HP102	Similar to the above specimen; initial grain size 20-50 μ, final 80-200 μ.
55	23	Nielsen, T.H. and Leipold, M.H.	1962	L	298-2073	LA-2	99.9 Al_2O_3, 0.1 MgO; specimen 3 in. long; grain size 48±3 μ; obtained from Norton Co.; isostatically pressed at 30 000 psi in wet hydrogen atmosphere; 91.0% theoretical density; expansion measured in air atmosphere; data reported from smoothed curve.
56*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	273-2224	LA-2	Similar to the above specimen; final grain size 66±4 μ; 1.57% permanent expansion; 92.5% theoretical density; zero-point correction of -0.016% determined by graphical interpolation.
57*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	2224-273	LA-2	The above specimen; expansion measured with decreasing temperature; zero-point correction of -1.513% determined by graphical interpolation.
58	24	Rachal, L.H.	1958	L	384-1306		Single crystal specimen; expansion measured along a-axis.
59	24	Rachal, L.H.	1958	L	384-1306		The above specimen; expansion measured along c-axis.
60	25	Baldock, P.T., Spindler, W.E., and Baker, T.W.	1968	X	294-2256	Specimen 1	99.9 pure; powdered specimen; cold pressed into brick, sintered at 2073 K for 4 hr; expansion measured along a-axis; lattice parameter at 293 K is 4.7583 Å.
61	25	Baldock, P.T., et al.	1968	X	789-2253	Specimen 1	The above specimen; expansion measured along c-axis; lattice parameter reported at 293 K is 12.993 Å.
62*	25	Baldock, P.T., et al.	1968	X	295-2078	Specimen 2	Similar to the above specimen; expansion measured along a-axis.
63	25	Baldock, P.T., et al.	1968	X	291-2078	Specimen 2	The above specimen; expansion measured along c-axis.
64	26	Coble, R.L. and Kingery, W.D.	1956		298-1473	Norton Co. 38X	Specimen 6 in. long; obtained from Norton Co.; slip cast from ground and acid-washed Al_2O_3; heating rate 4 C per min.
65	55	Itskevich, E.S., Voronovskii, A.N., Gavrilov, A.F., and Sukhaparov, V.A.	1967	L	88-307	Mikrolit TSM-322	Rockwel hardness 78.
66	28	Merriet, G.E.	1926	I	408-1020		99.9 pure specimen; fused, ground and sintered with binder of aluminum chloride; zero-point correction of 0.007% determined by graphical extrapolation.
67*	29	Merz, K.M., Kirchnev, H.P., and Smyth, H.T.	1960	X	299-1273		Reagent grade specimen; expansion measured along a-axis.
68*	29	Merz, K.M., et al.	1960	X	299-1273		The above specimen; expansion measured along c-axis.
69	30	Wechsler, A.E., and Denman, G.L.	1966	L	293-1923	Coors AD-99	Coors specimen; error reported 2-3%.
70*	31	Mason, C.R., Walton, J.D., Bowen, M.D., Teague, W.T., and Murphy, C.A.	1960	L	333-1257	No. 1169-2-3	Tubular specimen 0.953 cm I.D., 1.27 cm O.D., 3.8-5 cm long; prepared by spraying 20-50 μ particles onto brass tube, then removing brass by leaching in dilute nitric acid; density 2.91 g cm^{-3}.
71*	31	Mason, C.R., et al.	1960	L	314-1257	No. 1169-2-5	Similar to the above specimen; density 2.79 g cm^{-3}.

*Not shown in figure.

SPECIFICATION TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
72*	31	Mason, C.R., Walton, J.D., Bowen, M.D., Teague, W.T., and Murphy, C.A.	1960	L	314-1237	No. 1169-2-6	Similar to the above specimen; density 2.73 g cm^{-3}.
73	32	Filippi, F.T.	1963	L	300-1089	Al 995 Specimen 1	99.5 pure specimen 2 in. long; obtained from Western Gold and Platinum's Al 995.
74	32	Filippi, F.T.	1963	L	300-1089	Specimen 2	Similar to the above specimen.
75*	33	Kirchner, N.P. and Gruver, R.M.	1965	X	300-1273		Pure powdered specimen; expansion measured along a-axis; zero-point correction of 0.004% determined by graphical extrapolation.
76*	33	Kirchner, N.P. and Gruver, R.M.	1965	X	300-1273		The above specimen; expansion measured along c-axis; zero-point correction of 0.005% determined by graphical extrapolation.
77*	34	Atlas, L.M.	1958	T	298-1273		1.0 MnO, 1.0 TiO_2 added; hot-pressed specimen.
78*	35	Klomp, J.T. and Botden, Th.P.T.	1970	L	388-1173		Specimen prepared from pure oxide powder; sintered in air at 1423 K for 1.5 hr, broken up, milled 40 hr, mixed with nitrocellulose binder to form paste; melted and cast into rod; zero-point correction of -0.024% determined by graphical extrapolation.
79*	36	Floyd, J.R.	1970		303-939		99.3 Al_2O_3, 0.2 Fe_2O_3; calcined to 1922 K with 2 hr soak; sp. gr. 1.44.
80*	37	Crandall, W.B. and Ging, T.	1955	L	298-1673	AB-2	High strength Coor's grinding ball material.
81*	38	Floyd, T.R.	1965	L	373-1273		96 Al_2O_3 containing $MgO-SiO_2$ flux; average particle size 7 μ; subjected to various heat treatments; zero-point correction of 0.057% determined by graphical extrapolation.
82*	38	Floyd, T.R.	1965	L	373-1273		Similar to the above specimen except average particle size 23.5 μ; zero-point correction of 0.030% determined by graphical extrapolation.
83*	40	Ebert, H. and Tingwaldt, C.	1936	T	573-2073	Corundum	No details given.
84	27	Fieldhouse, T.B., Hedge, T.C., and Lang, T.I.	1958	T	300-1640		Polycrystalline specimen; zero-point correction of 0.003% determined by graphical extrapolation.
85*	27	Fieldhouse, T.B., et al.	1958	T	297-1781	Sapphire	Synthetic specimen; zero-point correction of 0.002% determined by graphical correction.
86*	44	Shakhtin, D.M., Levintovich, E.V., Pivovar, T.L., and Eliseeva, G.G.	1968	T	373-2273	Corundum	99.8 pure; rectangular block specimen 6-8 x 10-12 x 75-80 mm; two symmetrical channels of 4 x 6 x 30 mm running along each end; expansion measured in argon atmosphere.
87	47	Amatuni, A.N. and Shevchenko, E.B.	1966	L	373-1023	Corundum	99.9 pure; specimen 9.653 cm long; obtained from Kalinin Chernore Chinsk Chemical Plant, USSR; heated to 523 K cooled to room temperature; expansion measured parallel to crystallographic axis; mean values of two series of measurements.
88	47	Amatuni, A.N. and Shevchenko, E.B.	1966	L	373-1073	Corundum	Similar to the above specimen; 8.826 cm long at 293 K; expansion measured perpendicular to crystallographic axis; mean values of two series of measurements.
89*	48	Galdina, N.M. and Deri, A.	1962		273-1523	Corundum	99.2+ pure specimen; fused in 3-phase electric air furnace, melted, tested and poured into graphite molds; nearly free of glassy phase; zero-point correction of -0.008% determined by graphical interpolation.

*Not shown in figure.

SPECIFICATION TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
90*	49	Hunter, O., Jr.	1964	L	333-595	Corundum	99.98 pure; specimen 0.4 x 1.5 x 8.0 cm; heated under 3500 psi pressure to 1773 to 1973 K; cooled, ground into bar.
91	50	Strelkov, P.G., Lifanov, I.I., and Sherstyukov, N.G.	1966	L	273-1173	Corundum	Synthetic monocrystalline corundum of Chernorechenskii plat (Russia); specimen of leucosapphire with admixture of Cr_2O_3 up to 1.5%; expansion measured parallel to optic axis; zero-point correction of -0.0112%.
92	50	Strelkov, P.G., et al.	1966	L	273-1173	Corundum	Similar to the above specimen; expansion measured perpendicular to optic axis; zero-point correction of -0.0096%.
93*	74	Beals, R.J. and Cook, R.L.	1957	X	312-1473	Corundum	Reagent grade rhombohedral structured powder specimen; zero-point correction of 0.017% determined by graphical extrapolation.
94	52	Sharma, S.S.	1951	I	325-950	Corundum	Semi-cylindrical boule specimen; prepared from single crystal corundum; expansion measured parallel to optic axis.
95*	52	Sharma, S.S.	1951	I	326-958	Corundum	Similar to the above specimen; expansion measured perpendicular to optic axis.
96*	53	Heindl, R.A.	1933	L	301-2073	Corundum	95.5 Al_2O_3, 1.9 SiO_2, 1.9 CaO, 0.5 Fe_2O_3; artificial specimen; 0.875 in. square, 5.875 in. long; expansion measured in oxidizing and reducing atmosphere below 1273 K, in reducing atmosphere above 1273 K; reported error ± 5%; zero-point correction of 0.012% determined by graphical extrapolation.
97*	53	Heindl, R.A.	1933	L	301-2073	Corundum	Similar to the above specimen except heat treatment at 2073 K; zero-point correction of 0.012% determined by graphical extrapolation.
98	54	Strelkov, P.G., Lifanov, I.I., and Sherstyukov, N.G.	1966	L	391-1110	Corundum Specimen 5	Monocrystalline specimen; 10 mm^2 cross section, 2 to 30 mm long; tested on VNIIFTRI relative quartz dilatometer; expansion measured along optical axis.
99	54	Strelkov, P.G., et al.	1966	L	376-1028	Corundum Specimen 5	Similar to the above specimen; tested on VNIIM interferrometer dilatometer; expansion measured along optical axis.
100	54	Strelkov, P.G., et al.	1966	L	450-1129	Corundum Specimen 6	Similar to the above specimen; tested on VNIIFTRI relative quartz dilatometer; expansion measured perpendicular to optical axis.
101*	54	Strelkov, P.G., et al.	1966	L	376-1074	Corundum Specimen 6	Similar to the above specimen; tested on VNIIM interferometer dilatometer; expansion measured perpendicular to optical axis.
102	57	Shevlin, T.S. and Hauck, C.A.	1954	L	394-1073	Corundum Alcoa Grade T-61	0.05 soda added specimen; particle size -25 μ; obtained from Chamion Spark Plug Co.; acid leached; zero-point correction of 0.024% determined by graphical extrapolation.
103	57	Shevlin, T.S. and Hauck, C.A.	1954	L	1043-310	Corundum Alcoa Grade T-61	The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.015% determined by graphical extrapolation.
104*	273	Popper, P.	1966		323-1273	Code No. 8	98.47 Al_2O_3, 0.37 MgO, 0.34 SiO_2, 0.16 Fe_2O_3, 0.13 Na_2O, 0.10 CaO, 0.10 Cr_2O_3, 0.07 P_2O_5, 0.03 K_2O, < 0.001 TiO_2, < 0.01 Mn_3O_4; specimen 10 mm diameter, 50 mm long; density 3.35-3.80 g cm^{-3}.
105*	273	Popper, P.	1966		323-1273	Code No. 10	95.56 Al_2O_3, 1.98 Mn_3O_4, 1.52 TiO_2, 0.67 SiO_2, 0.24 Fe_2O_3, 0.15 MgO, 0.12 CaO, 0.05 K_2O, 0.04 Na_2O, 0.03 Cr_2O_3, 0.02 P_2O_5, < 0.01 Li_2O; specimen 10 mm diameter, 50 mm long; density 3.90 g cm^{-3}.
106*	273	Popper, P.	1966		323-1273	Code No. 5	98.79 Al_2O_3, 0.66 SiO_2, 0.20 Cr_2O_3, 0.17 MgO, 0.16 Fe_2O_3, 0.12 P_2O_5, 0.10 CaO, 0.03 Na_2O, 0.02 K_2O, 0.01 TiO_2; specimen 10 mm diameter, 50 mm long; density 3.87 g cm^{-3}.

*Not shown in figure.

SPECIFICATION TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
107*	273	Popper, P.	1966		323-1273	Code No. 6	98.63 Al_2O_3, 0.72 SiO_2, 0.39 MgO, 0.18 Fe_2O_3, 0.08 Cr_2O_3, 0.06 Na_2O, 0.06 CaO, 0.03 K_2O, 0.01 TiO_2, 0.01 P_2O_5; specimen 10 mm diameter, 50 mm long; density 3.87 g cm^{-3}.
108*	273	Popper, P.	1966		323-1273	Code No. 9	97.27 Al_2O_3, 1.52 SiO_2, 1.20 CaO, 0.15 Fe_2O_3, 0.05 Na_2O, 0.03 MgO, 0.01 K_2O, < 0.01 TiO_2, < 0.01 Cr_2O_3, < 0.01 Mn_3O_4, < 0.01 P_2O_5; similar to the above specimen.
109	11	Austin, J. B.	1931	I	293-1273		99.6+ Al_2O_3, 0.26 Fe_2O_3, 0.10 SiO_2; specimen aggregated of small crystals.
110	11	Austin, J. B.	1931	I	293-1273		Specimen cut from blue Indian sapphire; expansion measured parallel to principle axis.
111	11	Austin, J. B.	1931	I	293-1273		The above specimen; expansion measured perpendicular to principle axis.
112*	46	Conway, J. B.	1966	O	503-1073		99.99 pure; synthetic single crystal specimen; 0.5 cm diameter, 6.5 cm long; obtained from Linde Co.; expansion measured at GE-NMPO; c-axis orientation measured to be 64° ±1°; zero-point correction of 0.005% determined by graphical extrapolation.
113*	46	Conway, J. B.	1966	O	503-2054		The above specimen; expansion measured on second test; zero-point correction of 0.005% determined by graphical extrapolation.
114*	46	Conway, J. B.	1966	O	542-1850		The above specimen; expansion measured on third test; zero-point correction of 0.005% determined by graphical extrapolation.
115*	46	Conway, J. B.	1966	O	1175-1869		Similar to the above specimen except expansion measured at NBS; zero-point correction of 0.005% determined by graphical extrapolation.
116*	39	Conway, J. B. and Losekamp, A. C.	1965	T	298-1273	Sapphire	Single crystal; rod specimen 0.635 cm diameter, 6.35 cm long; expansion measured in vacuum; data from smoothed curve; zero-point correction of 0.003% determined by graphical extrapolation.
117*	39	Conway, J. B. and Losekamp, A. C.	1965	T	299-1273	Sapphire	The above specimen; expansion measured in helium atmosphere; data from smoothed curve; zero-point correction of 0.003% determined by graphical extrapolation.
118*	39	Conway, J. B. and Losekamp, A. C.	1965	T	473-1223	Sapphire	The above specimen; expansion measured in argon atmosphere; data reported by using 298 K as the reference temperature.
119*	336	Kamenetskii, A. B., Gul'ko, N. V., and Gladkaya, N. V.	1970	X	525-1473		99.7 Al_2O_3, 0.041 Fe_2O_3, 0.03 CaO, 0.028 SiO_2, 0.01 MgO; specimen prepared by semi-dry pressing finely dispersed powder of grain size < 2 μ at 1000 Kg cm^{-2} and fired at 2023 K; data from smoothed curve.
120*	584	Fitzer, E. and Weisenburger,	1972		293-1073		High purity specimen; average values from 16 laboratories.
121*	494	Ruh, E. and Wallace, W.	1963	L	293-1589		Specimen size 1 x 1 x 7 in.; overall accuracy ±3%; 99.4 Al_2O_3, 0.3 SiO_2; bulk density 180 pcf, apparent porosity 23.4%; data from smoothed curve.
122*	502	Yanagida, H. and Yamaguchi, G.	1964	X	293-1773		γ-aluminum oxide - tetragonal axial ratio of 1.0357, obtained from hydrothermal treatment, at 773 K and 50 atm for 20 hr of γ Al_2O_3 formed from dehydration of A100H in air at 973 K; specimen contained 7.5% water at 423 K, another specimen with axial ratio of 1.0183 was examined, it contained 3.5% water at 423 K; lattice dimension measured along d(400).
123*	502	Yanagida, H. and Yamaguchi, G.	1964	X	293-1173		Same as the above specimen; lattice dimension measured along d(004).

*Not shown in figure.

SPECIFICATION TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
124*	502	Yanagida, H. and Yamaguchi, G.	1964	X	293-1073		η-aluminum oxide obtained from dehydration at 973 K in air of bayerite $Al(OH)_3$ formed by neutralizing of aqueous solution of aluminum chloride by ammonia; lattice dimension measured along d(400).
125*	503	Burk, M.	1962	L	83-283		Specimen allowed to heat by ambient air to room temperature; specimen size 6 in. by 0.125 in. diameter; accuracy of dial indicator 0.0001 in.; composition 100 Al_2O_3, density (room temperature) 3.1 g cm^{-3}; porosity 18 to 21%.
126*	328	Yates, B., Cooper, R.F., and Pojur, A.F.	1972	I	100-760		α-Al_2O_3 trigonal symmetry group $\bar{3}m$ produced by Union Carbide Co., with impurities below 100 ppm; hollow cylinder 26.9 mm O.D., 22.0 mm I.D., 10 mm long; crystal orientation checked by back reflection: Laue photographs corrected with 0.5°; reported error 6% at 100 K to 3% at 300 K to 2% at 780 K; data obtained from smoothed values; expansion measured along c-axis.
127*	328	Yates, B., et al.	1972	I	100-780		Same as the above specimen; expansion measured along a-axis.
128*	504	Yim, W.M. and Paff, R.J.	1973	X	298-1076	Sapphire (α-Al_2O_3)	Sample obtained from single-crystal materials of high purity supplied by Insaco; spectrographic analysis: Cu, 1 ppm; Mg, 0.2 ppm; Ca, 10 ppm; Si, 15 ppm; measured lattice parameter hexagonal a-axis.
129*	504	Yim, W.M. and Paff, R.J.	1973	X	298-1076	Sapphire (α-Al_2O_3)	Same as the above specimen except hexagonal c-axis.
130*	527	Kircher, H.P., Gruver, R.M., and Ewig, R.A.	1970	X	293-1263		0.3 micron alumina from Adolf Meller Co., or A-16 alumina from Alcoa; expansion measured along c-axis.
131*	527	Kircher, H.P., et al.	1970	X	293-1265		Same as the above specimen; expansion measured along a-axis.
132*	593	Kukielka, H.	1972	X	303-1933		α-Al_2O_3 specimen; expansion measured along c-axis; 12.9866 Å reported at 303 K; 12.9860 Å at 293 K used for data conversion.
133*	593	Kukielka, H.	1972	X	303-1933		Same as the above specimen; expansion measured along a-axis; 4.9558 Å reported at 303 K; 4.7555 Å at 293 K used for data conversion.

* Not shown in figure.

DATA TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
298	0.003
573	0.187
873	0.441
1173	0.713
1473	1.062
1773	1.509

CURVE 2

T	$\Delta L/L_0$
298	0.003*
573	0.165
873	0.417
1173	0.721
1473	1.062*
1773	1.421

CURVE 3*

T	$\Delta L/L_0$
293	0.00
333	0.02
383	0.05
433	0.08
453	0.11
493	0.13
593	0.21
623	0.22
663	0.26
713	0.30
843	0.41
898	0.46
943	0.51
1003	0.55
1053	0.60
1113	0.66
1133	0.68
1283	0.80

CURVE 4*,‡

T	$\Delta L/L_0$
373	0.043
473	0.099
571	0.160
673	0.230
771	0.299
874	0.375
970	0.449

CURVE 5*

T	$\Delta L/L_0$
273	-0.01
1273	0.55

CURVE 6*

T	$\Delta L/L_0$
973	0.55

CURVE 7*

T	$\Delta L/L_0$
973	0.52

CURVE 8

T	$\Delta L/L_0$
367	0.04
476	0.11
566	0.19
707	0.31
1369	0.89
1588	1.08

CURVE 9‡

T	$\Delta L/L_0$
90	-0.066
118	-0.063
156	-0.055
212	-0.037
293	0.000
313	0.011
381	0.053
586	0.205
759	0.349
1009	0.571
1185	0.737
1365	0.918

CURVE 10‡

T	$\Delta L/L_0$
97	-0.064
136	-0.059
168	-0.051
207	-0.039
250	-0.021
293	0.000*
298	0.002*
341	0.027
374	0.048

CURVE 10 (cont.)‡

T	$\Delta L/L_0$
574	0.193
772	0.355
990	0.549
1161	0.711
1384	0.931
1471	1.020

CURVE 11‡

T	$\Delta L/L_0$
1280	0.858
1091	0.670
873	0.464
674	0.285
474	0.120

CURVE 12

T	$\Delta L/L_0$
317	0.010
476	0.112
675	0.269
876	0.437
1073	0.628
1275	0.812

CURVE 13

T	$\Delta L/L_0$
316	0.016
474	0.129
673	0.289
874	0.483
1073	0.667
1275	0.875

CURVE 14*

T	$\Delta L/L_0$
256	-0.019
421	0.055
650	0.223
834	0.361
1204	0.647
1966	1.318
2109	1.439
2128	1.417
2139	1.374

CURVE 15*

T	$\Delta L/L_0$
256	-0.019
421	0.055
650	0.223
834	0.361
1204	0.647
1915	1.223
1956	1.246
2006	1.218

CURVE 16*

T	$\Delta L/L_0$
256	-0.012
418	0.041
533	0.091
631	0.147
870	0.315
1106	0.489
1198	0.542
1302	0.593
1367	0.585

CURVE 17*

T	$\Delta L/L_0$
348	0.031
366	0.044
478	0.123
589	0.202
700	0.284
812	0.362
921	0.441
968	0.474

CURVE 18

T	$\Delta L/L_0$
273	-0.012
298	0.003
479	0.118*
685	0.282
891	0.444
1097	0.614
1303	0.759
1509	0.948
1715	1.105

CURVE 19

T	$\Delta L/L_0$
273	-0.012
298	0.009
479	0.113
685	0.295
891	0.457
1097	0.656
1303	0.836
1509	1.008
1715	1.188

CURVE 20*

T	$\Delta L/L_0$
348	0.0020
373	0.0025
398	0.0075
423	0.0225
448	0.0375
473	0.0575
498	0.0775
523	0.0975
548	0.1175
573	0.1325
598	0.1575
623	0.1775
648	0.1950
673	0.2175
698	0.2375
723	0.2625
748	0.2800
773	0.3050
798	0.3300
823	0.3525
848	0.3775
873	0.4000
898	0.4200
923	0.4450
948	0.4675
973	0.4875
998	0.5125
1023	0.5375
1048	0.5625
1073	0.5875
1098	0.6100
1123	0.6325
1148	0.6575
1173	0.6775

CURVE 20 (cont.)*

T	$\Delta L/L_0$
1198	0.7050
1223	0.7250
1248	0.7525
1273	0.7725

CURVE 21*

T	$\Delta L/L_0$
293	0.00
773	0.35
1073	0.64
1233	0.79

CURVE 22

T	$\Delta L/L_0$
1233	0.80
1073	0.65
773	0.36
293	0.00*

CURVE 23

T	$\Delta L/L_0$
293	0.000*
368	0.113
459	0.213
670	0.425
901	0.664
1222	1.004
1509	1.310
1763	1.541

CURVE 24*

T	$\Delta L/L_0$
298	0.0029
374	0.0472
471	0.1131
573	0.1899
669	0.2660
770	0.3502
870	0.4371
972	0.5371
1073	0.6204
1170	0.7110
1275	0.8106

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* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3 (continued)

T	$\Delta L/L_0$
CURVE 25*	
298	0.0029
376	0.0485
473	0.1150
574	0.1917
673	0.2688
773	0.3536
871	0.4377
971	0.5277
1074	0.6216
1172	0.7140
1274	0.8119
CURVE 26	
293	0.000*
343	0.217
468	0.050
547	0.194
633	0.222
780	0.325
880	0.440
1003	0.552
1126	0.655
1239	0.752
1342	0.780
1355	0.848
1451	0.942
1549	0.990
1561	1.068
1714	1.151*
1868	1.293
2023	1.152*
CURVE 27	
301	0.006
374	0.059
423	0.085
551	0.179
718	0.324
800	0.377
990	0.565
1079	0.641
1265	0.849
1339	0.921
1438	1.049

T	$\Delta L/L_0$
CURVE 28	
301	0.004
374	0.041
423	0.090
551	0.176
718	0.339
800	0.411
990	0.603
1079	0.709
1265	0.924
1339	1.014
1438	1.114
CURVE 29	
300	0.003*
406	0.055
584	0.107
802	0.378*
984	0.536
1226	0.780
1376	0.920
CURVE 30	
300	0.005*
406	0.079
584	0.252
802	0.425
984	0.606
1226	0.865
1376	1.047
CURVE 31	
293	0.000*
1273	0.793
1373	0.928
1473	1.073*
1573	1.203
1673	1.352
1773	1.480
1873	1.627
1973	1.764
2073	1.886*

T	$\Delta L/L_0$
CURVE 32	
373	0.035
473	0.101
573	0.171*
673	0.253
773	0.333
873	0.425
973	0.521
1073	0.619
1173	0.723*
1273	0.833
CURVE 33	
293	0.00*
1103	0.60
1153	0.64
1248	0.73
1333	0.83
1408	0.88
1498	0.98
1583	1.02
1663	1.12
1718	1.19
1783	1.26
1823	1.31
1883	1.36
1933	1.39
CURVE 34	
1933	1.44
1908	1.38
1838	1.27
1743	1.16
1653	1.05
1558	0.99
1453	0.90
1378	0.83*
1238	0.70
1148	0.62
293	0.00*
CURVE 35	
293	0.00*
1103	0.50

T	$\Delta L/L_0$
CURVE 35 (cont.)	
1188	0.58
1298	0.69
1413	0.79
1503	0.87
1688	1.09
1788	1.19
1883	1.29
1918	1.32
1958	1.31
CURVE 36	
1865	1.15
1761	1.04
1653	0.90
1541	0.83
1429	0.69
1317	0.58
1205	0.47
325	0.01
CURVE 37	
293	0.00*
1093	0.55
1138	0.59
1188	0.63
1238	0.68
1298	0.74
1358	0.80
1423	0.83
1453	0.86
1513	0.90
1548	0.97
1603	1.03
1663	1.07
1703	1.13
1753	1.16
1808	1.23
1858	1.27
1918	1.29
1978	1.35
2005	1.27*

T	$\Delta L/L_0$
CURVE 38	
2105	1.61*
2057	1.49*
1989	1.46
1933	1.44*
1909	1.39
1797	1.36
1693	1.28
1645	1.24
1589	1.17
1537	1.12
1493	1.08
1421	1.02
1373	1.00
1325	0.92
1273	0.88
1249	0.82
311	0.03
CURVE 39	
298	0.004
1098	0.574
1208	0.684
1363	0.834
1473	0.904
1583	1.004
1693	1.114
1798	1.224
1908	1.344
2028	1.454
2163	1.574
CURVE 40	
2123	1.624
2003	1.504
1888	1.414
1770	1.264
1673	1.154
1558	1.064
1443	1.014
1313	0.824
1183	0.704
298	0.004

T	$\Delta L/L_0$
CURVE 41‡	
473	0.110
673	0.233
873	0.372
1073	0.523
1273	0.681
CURVE 42‡	
473	0.107*
673	0.226
873	0.366
1073	0.515
1273	0.672
CURVE 43	
100	-0.0629
150	-0.0564
200	-0.0428
250	-0.0224
300	0.0036
350	0.0343
400	0.0686
450	0.1057
500	0.1450
550	0.1861
600	0.2286
650	0.2723
700	0.3169
750	0.3623
800	0.4084*
900	0.5021
1000	0.5974
1100	0.6940
CURVE 44	
100	-0.0537
150	-0.0484
200	-0.0369
250	-0.0193
300	0.0034*
350	0.0303
400	0.0606
450	0.0937
500	0.1288

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3 (continued)

T	$\Delta L/L_0$
CURVE 44 (cont.)	
550	0.1657
600	0.2039
650	0.2433
700	0.2835
750	0.3245
800	0.3662
900	0.4510
1000	0.5374
1100	0.6250
CURVE 45	
100	-0.0619*
150	-0.0551
200	-0.0415
250	-0.0216*
300	0.0035
350	0.0327
400	0.0651
450	0.1001
500	0.1369
550	0.1754
600	0.2151
650	0.2558
700	0.2973
750	0.3396
800	0.3824
900	0.4695
1000	0.5581
1100	0.6479
CURVE 46*	
294	0.010
297	0.002
477	0.150
477	0.164
671	0.343
675	0.323
876	0.495
879	0.510
1077	0.670
1278	0.874
1279	0.903
1471	1.009

T	$\Delta L/L_0$
CURVE 47*	
294	0.00
1672	1.07
CURVE 48	
298	0.004*
673	0.302
873	0.473*
1073	0.664
1273	0.865
1473	1.070*
1673	1.260
1773	1.360
1873	1.470
1973	1.620
CURVE 49*	
1773	1.428
1673	1.323
1473	1.103
1273	0.882
1073	0.664
873	0.473
673	0.302
298	0.004
CURVE 50	
298	0.004*
673	0.302*
873	0.473*
1073	0.664*
1273	0.866*
1473	1.087
1673	1.312
1873	1.552
1973	1.682
2073	1.867
CURVE 51*	
1973	1.682
1873	1.580
1673	1.339
1473	1.087
1273	0.853

T	$\Delta L/L_0$
CURVE 51 (cont.)*	
1073	0.664
873	0.473
673	0.302
298	0.004
CURVE 52*	
298	0.004
673	0.302
873	0.473
1073	0.664
1273	0.867
1473	1.081
1673	1.308
1873	1.556
2073	1.972
CURVE 53*	
1773	1.456
1673	1.325
1473	1.081
1273	0.867
1073	0.664
873	0.473
673	0.302
298	0.004
CURVE 54*	
298	0.004
673	0.302
873	0.473
1073	0.664
1273	0.864
1473	1.078
1673	1.307
1873	1.534
2073	1.732
CURVE 55	
298	0.004*
673	0.297
873	0.480
1073	0.679*
1273	0.894

T	$\Delta L/L_0$
CURVE 55 (cont.)	
1473	1.117
1673	1.352*
1873	1.591
2073	1.833*
CURVE 56*	
273	-0.02
673	0.29
1073	0.67
1473	1.11
1873	1.58
2073	1.83
2139	1.95
2194	2.09
2224	2.27
2224	3.50
CURVE 57*	
2224	2.02
1873	1.61
1473	1.12
1073	0.68
673	0.32
273	-0.003
CURVE 58‡	
384.7	0.048
451.2	0.083
541.6	0.131
653.2	0.196
738.2	0.248
851.2	0.318
952.2	0.382
1023.7	0.430
1101.7	0.483
1194.2	0.547
1306.7	0.628
CURVE 59‡	
384.7	0.059
451.2	0.102*
541.6	0.163
653.2	0.242

T	$\Delta L/L_0$
CURVE 59 (cont.)‡	
738.2	0.304
851.2	0.388
952.2	0.464
1023.7	0.521
1101.7	0.583
1194.2	0.659
1306.7	0.753
CURVE 60	
294	0.006*
783	0.382
1145	0.698
1481	0.969
1782	1.259
1995	1.431
2256	1.673*
CURVE 61	
789	0.377
1143	0.762
1484	1.031
1783	1.401
1994	1.547
2253	1.655*
CURVE 62*	
295	0.017
605	0.202
931	0.485
1282	0.813
1798	1.297
1853	1.276
2078	1.601
CURVE 63	
291	0.077
604	0.246
929	0.569
1287	0.947
1799	1.432
1848	1.385
2078	1.832*

T	$\Delta L/L_0$
CURVE 64‡	
298	0.003*
473	0.106
673	0.243*
873	0.398
1073	0.569
1273	0.751
1473	0.941
CURVE 65‡	
88	-0.064
104	-0.062
131	-0.060
168	-0.052
203	-0.041
236	-0.028
259	-0.017
280	-0.007
293	0.000
307	0.007
CURVE 66	
408	0.070
562	0.180
701	0.291
831	0.401
908	0.471
954	0.514
1020	0.571
CURVE 67*	
299	0.005
473	0.118
673	0.276
873	0.442
1073	0.619
1273	0.795
CURVE 68*	
299	0.005
473	0.134
673	0.294
873	0.482
1073	0.669
1273	0.859

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3 (continued)

T	$\Delta L/L_0$
CURVE 69	
293	0.000*
405	0.066*
548	0.171*
676	0.253*
738	0.302
791	0.324
877	0.364*
952	0.411
1019	0.459
1084	0.513
1131	0.560
1190	0.622
1296	0.744
1400	0.854
1543	0.989
1689	1.147
1796	1.251
1923	1.369
CURVE 70*	
333	0.005
437	0.027
491	0.047
546	0.072
601	0.101
708	0.180
818	0.260
926	0.355
1201	0.586
1257	0.642
CURVE 71*	
314	0.002
437	0.044
545	0.090
654	0.158
762	0.232
873	0.318
1036	0.437
1089	0.481
1147	0.532
1257	0.618

T	$\Delta L/L_0$
CURVE 72*	
314	0.002
437	0.063
546	0.117
654	0.183
763	0.254
873	0.341
981	0.431
1090	0.516
1145	0.558
1237	0.626
CURVE 73	
300	0.004*
381	0.049*
443	0.087
462	0.101*
513	0.137
559	0.171
596	0.204*
630	0.229
680	0.272
721	0.304
755	0.331*
793	0.364
848	0.412
879	0.435*
925	0.471
966	0.511
993	0.548*
1054	0.606
1089	0.632
CURVE 74	
300	0.004*
381	0.049*
422	0.074
510	0.138*
554	0.169*
588	0.194
627	0.222
679	0.265
716	0.296
771	0.335*
843	0.387

T	$\Delta L/L_0$
CURVE 74 (cont.)	
876	0.412*
922	0.455
959	0.506*
999	0.557*
1063	0.623
1089	0.648
CURVE 75*	
300	0.004
473	0.111
673	0.275
873	0.437
1073	0.618
1273	0.807
CURVE 76*	
300	0.005
473	0.126
673	0.284
873	0.481
1073	0.664
1273	0.859
CURVE 77*	
298	0.0038
973	0.52
1273	0.76
CURVE 78*	
388	0.050
470	0.102
579	0.183
673	0.264
778	0.343
873	0.429
979	0.515
1077	0.598
1132	0.643
1173	0.686

T	$\Delta L/L_0$
CURVE 79*	
303	0.005
373	0.043
473	0.102
573	0.168
673	0.235
773	0.307
873	0.380
939	0.434
CURVE 80*	
298	0.0030
473	0.11
673	0.25
873	0.41
1073	0.58
1273	0.78
1473	1.01
1573	1.17
1673	1.19
CURVE 81*	
373	0.057
473	0.136
573	0.220
673	0.307
773	0.398
873	0.485
973	0.577
1073	0.675
1173	0.776
1273	0.873
CURVE 82*	
373	0.061
473	0.143
573	0.227
673	0.304
773	0.389
873	0.479
973	0.575
1073	0.669
1173	0.771
1273	0.872

T	$\Delta L/L_0$
CURVE 83*	
573	0.200
773	0.365
973	0.540
1173	0.725
1273	0.840
1373	0.930
1573	1.130
1773	1.335
1973	1.540
2073	1.655
CURVE 84	
300	0.003*
439	0.064
554	0.146
618	0.206
686	0.251
761	0.328
818	0.428
913	0.470
962	0.535
1018	0.573*
1101	0.671
1157	0.755
1235	0.809*
1326	0.931
1406	0.999
1470	1.077*
1554	1.208
1640	1.294
CURVE 85*	
297	0.002
339	0.024
356	0.042
369	0.073
411	0.132
448	0.149
463	0.151
470	0.157
489	0.163
505	0.170
529	0.175
574	0.232

T	$\Delta L/L_0$
CURVE 85 (cont.)*	
633	0.277
644	0.272
675	0.306
731	0.352
740	0.361
787	0.413
854	0.467
912	0.521
960	0.549
983	0.589
1011	0.603
1036	0.640
1069	0.655
1090	0.686
1118	0.716
1159	0.755
1341	0.941
1375	0.962
1414	1.010
1446	1.035
1462	1.069
1531	1.146
1598	1.242
1651	1.288
1721	1.354
1781	1.444
CURVE 86*	
373	0.080
473	0.100
573	0.180
673	0.250
773	0.305
873	0.400
973	0.500
1073	0.600
1173	0.700
1273	0.805
1373	0.918
1473	1.020
1573	1.150
1673	1.250
1773	1.360
1873	1.480
1973	1.590

*Not shown in figure.

DATA TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3 (continued)

T	$\Delta L/L_0$
CURVE 86 (cont.)*	
2073	1.700
2173	1.810
2273	1.980
CURVE 87	
373	0.0502*
473	0.1237*
573	0.2040
673	0.2910*
773	0.3820
823	0.4271
873	0.4755
923	0.5235
973	0.5413
1023	0.6164
CURVE 88	
373	0.0448
473	0.1110*
573	0.1848
673	0.2620*
773	0.3439
823	0.3857
873	0.4290*
923	0.4728
973	0.5165*
1023	0.5606
1073	0.6048
CURVE 89*	
273	-0.008
523	0.147
773	0.339
1023	0.545
1273	0.745
1523	0.952
CURVE 90*	
333	0.016
350	0.023
382	0.045
414	0.068
454	0.096

T	$\Delta L/L_0$
CURVE 90 (cont.)*	
490	0.122
525	0.147
562	0.172
595	0.198
CURVE 91	
273	-0.0112*
283	-0.0057
293	0.0000*
303	0.0059*
313	0.0119*
323	0.0180*
333	0.0242*
343	0.0305*
353	0.0370*
363	0.0435
373	0.0501*
383	0.0569*
393	0.0638*
403	0.0708*
413	0.0779*
423	0.0851*
433	0.0924
443	0.0998*
453	0.1073*
463	0.1149
473	0.1226*
483	0.1303
493	0.1381*
503	0.1460*
513	0.1540*
523	0.1620
533	0.1701*
543	0.1783*
553	0.1865*
563	0.1948
573	0.2032*
583	0.2117
593	0.2203*
603	0.2290*
613	0.2378
623	0.2467*
633	0.2556
643	0.2645*
653	0.2734*
663	0.2823

T	$\Delta L/L_0$
CURVE 91 (cont.)	
673	0.2912*
683	0.3001*
693	0.3090
703	0.3179*
713	0.3269*
723	0.3360
733	0.3451*
743	0.3542
753	0.3633*
763	0.3724*
773	0.3817
783	0.3908*
793	0.4000
803	0.4092*
813	0.4184*
823	0.4277*
833	0.4371
843	0.4466*
853	0.4561*
863	0.4656
873	0.4751*
883	0.4846
893	0.4941*
903	0.504*
913	0.5136
923	0.5226*
933	0.5321
943	0.5417*
953	0.5513*
963	0.5609
973	0.5705*
983	0.5801*
993	0.5897*
1003	0.5993*
1013	0.6089
1023	0.6185*
1033	0.6281
1043	0.6377*
1053	0.6474*
1063	0.6571
1073	0.6668*
1083	0.6765*
1093	0.6862
1103	0.6959*
1113	0.7056*
1123	0.7154
1133	0.7253*

T	$\Delta L/L_0$
CURVE 91 (cont.)	
1143	0.7353
1153	0.7453*
1163	0.7553*
1173	0.7653
CURVE 92	
273	-0.0096
283	-0.0049*
293	0.0000*
303	0.0051*
313	0.0104*
323	0.0159
333	0.0215*
343	0.0272*
353	0.0330*
363	0.0389
373	0.0449*
383	0.0510*
393	0.0572*
403	0.0635*
413	0.0699*
423	0.0764
433	0.0830*
443	0.0897*
453	0.0965*
463	0.1034
473	0.1104*
483	0.1174*
493	0.1244*
503	0.1315*
513	0.1387*
523	0.1460
533	0.1534*
543	0.1608*
553	0.1683*
563	0.1759
573	0.1836*
583	0.1914*
593	0.1992*
603	0.2070*
613	0.2148*
623	0.2227
633	0.2306*
643	0.2386*
653	0.2467
663	0.2548

T	$\Delta L/L_0$
CURVE 92 (cont.)	
673	0.2629*
683	0.2710*
693	0.2791*
703	0.2873*
713	0.2955*
723	0.3037
733	0.3119*
743	0.3201*
753	0.3283*
763	0.3365*
773	0.3447*
783	0.3529
793	0.3611*
803	0.3694*
813	0.3777
823	0.3860*
833	0.2943
843	0.4026
853	0.4109*
863	0.4193*
873	0.4277*
883	0.4361*
893	0.4446*
903	0.4532*
913	0.4618
923	0.4704*
933	0.4791*
943	0.4879
953	0.4967*
963	0.5057*
973	0.5143*
983	0.5231*
993	0.5320*
1003	0.5410*
1013	0.5500
1023	0.5590*
1033	0.5680*
1043	0.5770*
1053	0.5860
1063	0.5950*
1073	0.6040*
1083	0.6131*
1093	0.6222
1103	0.6313*
1113	0.6404*
1123	0.6495*
1133	0.6587*

T	$\Delta L/L_0$
CURVE 92 (cont.)	
1143	0.6679
1153	0.6771
1163	0.6863
1173	0.6955
CURVE 93*	
312	0.017
473	0.174
673	0.367
873	0.562
1073	0.754
1273	0.951
1473	1.143
CURVE 94‡	
324.9	0.022
367.9	0.052*
408.5	0.081
447.1	0.110*
483.4	0.138*
523.9	0.169*
567.1	0.204
608.4	0.239*
648.2	0.274*
690.6	0.312*
735.3	0.354
778.5	0.395*
820.3	0.436
860.8	0.478*
903.1	0.522
950.1	0.574
CURVE 95*, ‡	
326.8	0.020
368.8	0.044
408.0	0.068
444.9	0.092
480.3	0.115
518.4	0.141
558.8	0.169
597.2	0.197
633.9	0.226
672.8	0.257
713.8	0.290

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3 (continued)

T	$\Delta L/L_0$
CURVE 95 (cont.)*, ‡	
752.8	0.324
790.5	0.357
826.9	0.390
867.7	0.429
912.4	0.474
957.6	0.521
CURVE 96*	
301	0.012
386	0.059
469	0.120
587	0.208
680	0.292
782	0.369
802	0.400
849	0.433
894	0.476
978	0.560
1084	0.649
1173	0.744
1282	0.836
1375	0.907
1484	0.982
1569	1.054
1645	1.102
1756	1.158
1837	1.127
1908	1.074
1939	1.013
2005	0.693
2073	0.359
CURVE 97*	
301	0.012
386	0.059
469	0.120
587	0.208
680	0.292
782	0.369
802	0.400
849	0.433
894	0.476
978	0.560
1084	0.649
1173	0.744

T	$\Delta L/L_0$
CURVE 97 (cont.)*	
1282	0.858
1391	0.971
1497	1.061
1580	1.153
1677	1.237
1754	1.308
1845	1.328
1912	1.346
1982	1.435
2044	1.451
2073	1.444
CURVE 98	
391	0.074
424	0.090*
485	0.140
537	0.180
586	0.222
638	0.257*
685	0.314
736	0.334
784	0.398
839	0.433*
894	0.500
997	0.600
1110	0.707
CURVE 99	
376	0.063
378	0.069*
468	0.142
474	0.144*
574	0.216
576	0.219*
666	0.296*
677	0.296*
775	0.381*
824	0.428*
874	0.473*
877	0.475*
918	0.515*
922	0.519
974	0.553*
974	0.561

T	$\Delta L/L_0$
CURVE 99 (cont.)	
1022	0.610*
1028	0.614*
CURVE 100	
450	0.103
498	0.132*
537	0.149
596	0.190
742	0.305
786	0.348*
838	0.393
958	0.482
1000	0.520*
1129	0.638
CURVE 101*	
376	0.047
470	0.113
474	0.115
576	0.182
675	0.260
677	0.266
772	0.340
821	0.383
876	0.421
922	0.459
974	0.508
1025	0.551
1074	0.607
CURVE 102	
394.	0.069
433.	0.100
473	0.119*
510	0.139*
538	0.173
573	0.194*
603	0.215*
673	0.268*
773	0.350*
833	0.402*
883	0.440
933	0.484
1005	0.552*

T	$\Delta L/L_0$
CURVE 102 (cont.)	
1053	0.588
1073	0.616*
CURVE 103	
1043	0.552
1004	0.520
973	0.492
930	0.450*
896	0.422
877	0.415*
810	0.351
743	0.296
669	0.237
315	0.014*
310	0.008
CURVE 104*	
323	0.023
873	0.438
1273	0.780
CURVE 105*	
323	0.024
873	0.462
1273	0.804
CURVE 106*	
323	0.023
873	0.445
1273	0.795
CURVE 107*	
323	0.023
873	0.435
1273	0.782
CURVE 108*	
323	0.023
873	0.438
1273	0.783

T	$\Delta L/L_0$
CURVE 109	
293	0.000*
323	0.010*
373	0.032*
423	0.055
473	0.085
523	0.110
573	0.140
623	0.170
673	0.200
723	0.231
773	0.265
823	0.300
873	0.332
923	0.368
973	0.395
1023	0.430
1073	0.463
1123	0.495
1173	0.528
1223	0.558
1273	0.590
CURVE 110	
293	0.000*
323	0.020*
373	0.055*
423	0.090*
473	0.130*
523	0.175
573	0.218*
623	0.258
673	0.302
723	0.350
773	0.400
823	0.444
873	0.490*
923	0.545
973	0.593
1023	0.640
1073	0.685
1123	0.730
1173	0.780
1223	0.832
1273	0.885

T	$\Delta L/L_0$
CURVE 111	
293	0.000*
323	0.015*
373	0.044*
423	0.078*
473	0.112*
523	0.150*
573	0.192*
623	0.233*
673	0.278*
723	0.325
773	0.370
823	0.410
873	0.455
923	0.500
973	0.545
1023	0.588
1073	0.632*
1123	0.678
1173	0.725*
1223	0.770
1273	0.815*
CURVE 112*	
503	0.166
652	0.257
789	0.352
929	0.523
1073	0.618
CURVE 113*	
503	0.134
672	0.267
929	0.489
1108	0.618
1203	0.708
1523	1.005
1667	1.168
1877	1.368
2054	1.598
CURVE 114*	
542	0.164
761	0.347
892	0.459

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 35. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3 (continued)

CURVE 114 (cont.)*

T	$\Delta L/L_0$
1077	0.592
1224	0.712
1472	0.949
1625	1.122
1850	1.360

CURVE 115*

T	$\Delta L/L_0$
1175	0.672
1274	0.769
1369	0.863
1467	0.960
1569	1.059
1664	1.146
1775	1.278
1869	1.401

CURVE 116*

T	$\Delta L/L_0$
298	0.003
407	0.076
542	0.180
725	0.331
843	0.438
1075	0.652
1273	0.845

CURVE 117*

T	$\Delta L/L_0$
299	0.003
387	0.040
477	0.099
611	0.194
764	0.308
902	0.426
1043	0.559
1180	0.692
1273	0.784

CURVE 118*

T	$\Delta L/L_0$
473	-0.224
473	-0.148
587	-0.084
604	-0.110
773	0.053

CURVE 118 (cont.)*

T	$\Delta L/L_0$
917	0.188
1043	0.322
1223	0.422

CURVE 119*

T	$\Delta L/L_0$
525	0.15
573	0.18
673	0.23
773	0.30
873	0.37
973	0.46
1073	0.53
1173	0.65
1273	0.77
1373	0.91
1473	1.03

CURVE 120*

T	$\Delta L/L_0$
293	0.00
573	0.19
773	0.35
973	0.54
1073	0.64

CURVE 121*

T	$\Delta L/L_0$
293	0.000
366	0.057
478	0.142
589	0.223
700	0.315
811	0.414
922	0.523
1033	0.629
1145	0.745
1256	0.854
1367	0.971
1478	1.076
1589	1.163

CURVE 122*

T	$\Delta L/L_0$
293	0.0000
403	0.1399

CURVE 122 (cont.)*

T	$\Delta L/L_0$
543	0.3697
673	0.1999
873	-0.5046
1073	-0.4846
1173	-0.4047

CURVE 123*

T	$\Delta L/L_0$
293	0.0000
403	-0.0207
543	0.0776
673	0.0310
873	-0.1294
1073	-0.1397
1173	0.0207

CURVE 124*

T	$\Delta L/L_0$
293	0.0000
403	0.1010
543	0.1616
673	0.2071
873	0.3738
1073	0.6010

CURVE 125*,‡

T	$\Delta L/L_0$
83	-0.084
103	-0.078
123	-0.071
143	-0.065
163	-0.059
183	-0.052
203	-0.045
223	-0.038
243	-0.029
263	-0.019
283	-0.006

CURVE 126*,‡

T	$\Delta L/L_0$
100	-0.066
120	-0.064
140	-0.060
160	-0.056
180	-0.051

CURVE 126 (cont.)*,‡

T	$\Delta L/L_0$
200	-0.044
220	-0.036
240	-0.027
260	-0.018
280	-0.007
300	0.004
320	0.016
340	0.028
360	0.041
380	0.054
400	0.068
420	0.083
440	0.097
460	0.113
480	0.128
500	0.144
520	0.160
540	0.176
560	0.192
580	0.209
600	0.226
620	0.243
640	0.260
660	0.277
680	0.295
700	0.313
720	0.330
740	0.348
760	0.366

CURVE 127*,‡

T	$\Delta L/L_0$
100	-0.057
120	-0.056
140	-0.053
160	-0.049
180	-0.045
200	-0.039
220	-0.032
240	-0.024
260	-0.016
280	-0.006
300	0.003
320	0.014
340	0.025
360	0.037

CURVE 127 (cont.)*,‡

T	$\Delta L/L_0$
380	0.048
400	0.061
420	0.074
440	0.087
460	0.100
480	0.114
500	0.128
520	0.142
540	0.157
560	0.172
580	0.187
600	0.203
620	0.218
640	0.234
660	0.250
680	0.266
700	0.282
720	0.298
740	0.315
760	0.331
780	0.347

CURVE 128*

T	$\Delta L/L_0$
298	0.0021
429	0.1009
623	0.2396
769	0.3447
923	0.4498
1076	0.5738

CURVE 129*

T	$\Delta L/L_0$
298	0.0008
429	0.1286
623	0.2865
769	0.4028
923	0.5022
1076	0.6485

CURVE 130*

T	$\Delta L/L_0$
293	0.000
473	0.124
673	0.280
873	0.473

CURVE 130 (cont.)*

T	$\Delta L/L_0$
1068	0.655
1263	0.859

CURVE 131*

T	$\Delta L/L_0$
293	0.000
479	0.114
673	0.271
873	0.440
1067	0.629
1265	0.813

CURVE 132*

T	$\Delta L/L_0$
303	0.005
1423	1.028
1723	1.337
1933	1.566

CURVE 133*

T	$\Delta L/L_0$
303	0.006
1423	0.948
1723	1.243
1933	1.428

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 35. COEFFICIENT OF THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE Al_2O_3

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

CURVE 4*, ‡

T	α
373	5.41
473	5.62
571	6.24
673	6.83
771	7.03
874	7.44
970	7.67

CURVE 9‡

T	α
90	0.82
118	1.25
156	2.68
212	3.85
293	5.44
313	5.70*
381	6.69*
586	8.12*
759	8.52*
1009	9.24*
1185	9.67*
1365	10.04*

CURVE 10‡

T	α
97	0.45
136	2.33
168	2.56
207	3.62
250	4.63
293	5.44*
298	5.51
341	6.09*
374	6.59*
574	7.89*
772	8.49*
990	9.32*
1161	9.64*
1384	10.07*
1471	10.47*

CURVE 11*, ‡

T	α
1280	9.90
1091	9.49
873	8.99

CURVE 11 (cont.)*, ‡

T	α
674	8.21
474	7.23

CURVE 41*, ‡

T	α
473	5.61
673	6.64
873	7.32
1073	7.72
1273	8.09

CURVE 42*, ‡

T	α
473	5.25
673	6.63
873	7.35
1073	7.64
1273	8.03

CURVE 58*, ‡

T	α
384.7	5.17
451.2	5.26
541.6	5.58
653.2	6.06
738.2	6.10
851.2	6.30
952.2	6.42
1023.7	6.78
1101.7	6.87
1194.2	7.04
1306.7	7.25

CURVE 59*, ‡

T	α
384.7	6.31
451.2	6.60
541.6	6.83
653.2	7.28
738.2	7.31
851.2	7.55
952.2	7.68
1023.7	8.02
1101.7	8.11
1194.2	8.24
1306.7	8.47

CURVE 64*, ‡

T	α
298	5.4
473	6.4
673	7.3
873	8.2
1073	8.9
1273	9.3
1473	9.7

CURVE 65‡

T	α
88	0.53
104	0.81
131	1.32
168	2.58
203	3.66
236	4.40
259	4.88
280	5.17
293	5.29
307	5.39*

CURVE 94*, ‡

T	α
324.9	6.85
367.9	7.05
408.5	7.36
447.1	7.53
483.4	7.72
523.9	7.95
567.1	8.31
608.4	8.60
648.2	8.85
690.6	9.11
735.3	9.46
778.5	9.73
820.3	10.02
860.8	10.36
903.1	10.73
950.1	11.15

CURVE 95*, ‡

T	α
326.8	5.72
368.8	5.98
408.0	6.24
444.9	6.46

CURVE 95 (cont.)*, ‡

T	α
480.3	6.65
518.4	6.90
558.8	7.23
597.2	7.51
633.9	7.86
672.8	8.04
713.8	8.39
752.8	8.71
790.5	9.01
826.9	9.32
867.7	9.73
912.4	10.16
957.6	10.65

CURVE 125‡

T	α
83	3.01
103	3.17
123	3.17
143	3.17
163	3.17
183	3.17
203	3.54
223	4.03
243	4.63
263	5.23
283	7.70*

CURVE 126‡

T	α
100	0.85
120	1.35
140	1.90
160	2.50
180	3.08
200	3.64
220	4.14
240	4.60
260	5.02
280	5.39
300	5.74
320	6.05*
340	6.34*
360	6.61*
380	6.86*
400	7.04*

CURVE 126 (cont.)‡

T	α
420	7.29*
440	7.46*
460	7.63*
480	7.78*
500	7.91*
520	8.05*
540	8.17*
560	8.29*
580	8.39*
600	8.48*
620	8.56*
640	8.64*
660	8.70*
680	8.79*
700	8.86*
720	8.94*
740	9.02*
760	9.10*

CURVE 127‡

T	α
100	0.67
120	1.10
140	1.56
160	2.10
180	2.65
200	3.16
220	3.65
240	4.06
260	4.45
280	4.79
300	5.10
320	5.39*
340	5.65*
360	5.88*
380	6.09*
400	6.29*
420	6.48*
440	6.65*
460	6.81*
480	6.97*
500	7.12*
520	7.26*
540	7.39*
560	7.51*
580	7.64*

CURVE 127 (cont.)‡

T	α
600	7.74*
620	7.83*
640	7.90*
660	7.98*
680	8.05*
700	8.10*
720	8.16*
740	8.20*
760	8.22*
780	8.24*

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 36. THERMAL LINEAR EXPANSION OF BARIUM OXIDE BaO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	43	Eisenstein, A.	1946	X	293, 1148		Cubic crystal specimen; reported error ±12%.

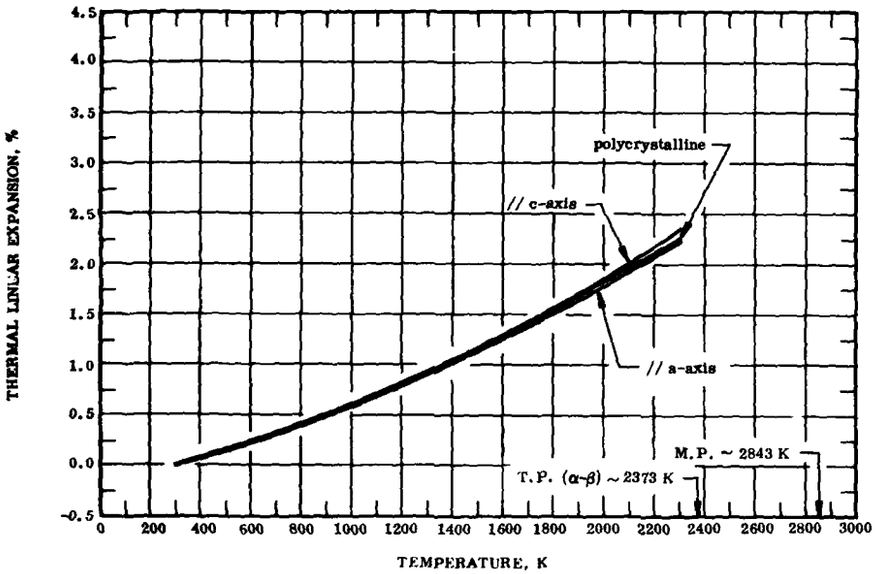
DATA TABLE 36. THERMAL LINEAR EXPANSION OF BARIUM OXIDE BaO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
1148	1.522

* No figure given.

FIGURE AND TABLE NO. 37R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF BERYLLIUM OXIDE BeO



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	6.3
350	0.043	0.039	0.037	6.6
400	0.082	0.070	0.070	6.9
500	0.160	0.138	0.143	7.5
600	0.242	0.214	0.220	8.0
700	0.327	0.296	0.304	8.6
800	0.416	0.385	0.393	9.2
900	0.508	0.480	0.487	9.7
1000	0.605	0.580	0.586	10.2
1100	0.706	0.686	0.690	10.6
1200	0.811	0.796	0.799	11.1
1300	0.921	0.912	0.912	11.6
1400	1.037	1.031	1.030	12.0
1500	1.157	1.154	1.152	12.4
1600	1.284	1.280	1.278	12.8
1700	1.416	1.408	1.408	13.2
1800	1.555	1.540	1.541	13.6
1900	1.700	1.673	1.679	13.9
2000	1.851	1.808	1.819	14.2
2100	2.010	1.944	1.963	14.5
2200	2.176	2.081	2.110	14.8
2300	2.349	2.219	2.260	15.1

REMARKS

The recommended values for the axial thermal expansion are based on the data for pure samples. The values for the polycrystalline sample are based on the data reported in curves 1, 19, 20, 22, 66 and 67. These values are considered accurate to within ±3% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -0.208 + 6.837 \times 10^{-4}\, T + 8.573 \times 10^{-8}\, T^2 + 4.369 \times 10^{-11}\, T^3$

// a-axis: $\Delta L/L_0 = -0.127 + 3.030 \times 10^{-4}\, T + 4.654 \times 10^{-7}\, T^2 - 6.733 \times 10^{-11}\, T^3$

polycrystalline: $\Delta L/L_0 = -0.157 + 4.433 \times 10^{-4}\, T + 3.276 \times 10^{-7}\, T^2 - 2.754 \times 10^{-11}\, T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±5%.

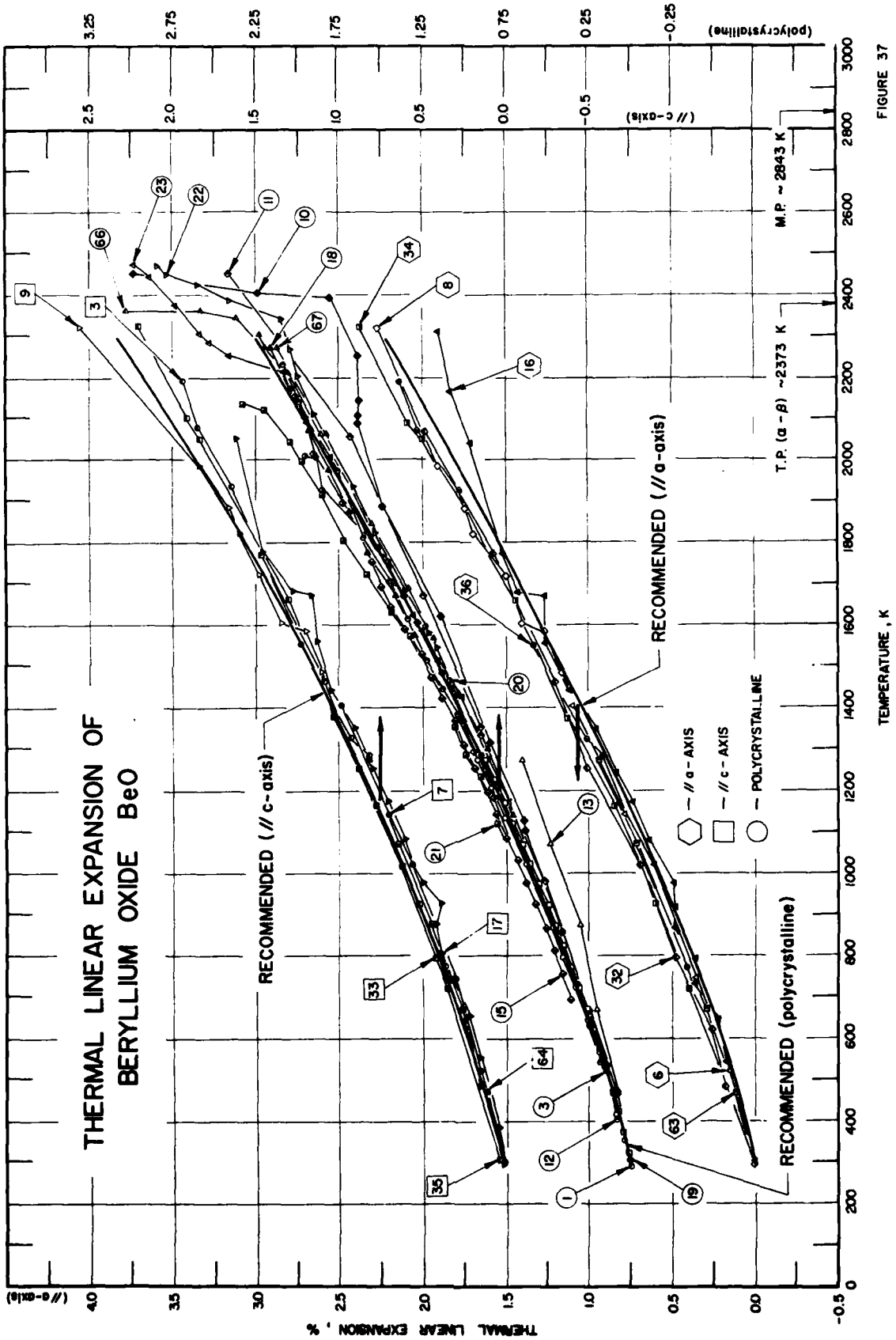

THERMAL LINEAR EXPANSION OF BERYLLIUM OXIDE BeO
RECOMMENDED (// c-axis)
RECOMMENDED (// a-axis)
RECOMMENDED (polycrystalline)
M.P. ~ 2843 K
T.P. (α - β) ~2373 K
— // a - AXIS
— // c - AXIS
— POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
(// c-axis)
(polycrystalline)
(// a-axis)

FIGURE 37

SPECIFICATION TABLE 37. THERMAL LINEAR EXPANSION OF BERYLLIUM OXIDE BeO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	58	Turner, D.N. and Smith, P.C.	1965	L	292-1272	Brush UOX grade beryllia	High purity powder specimen; 4 mm dia, 20 mm long; prepared by isostatic pressing powder at 20 t.s.i., sintered in dry nitrogen at 1500 C 1 hr; surface and centerless grinding to size; density 2.68 - 2.94 g cm^{-3}; reported error 5%.
2*	59	Bobrowsky, A.R.	1949		300,866		No details given.
3	60	White, H.E. and Shremp, R.M.	1939	L	298-1273		Exceptionally pure crystalline specimen; 0.02 Fe_2O_3, 0.02 SiO_2, 0.004 Al_2O_3; obtained from Brush Beryllium Co; mixed with small amount of dextrine pressed into bar, and fired to cone 18; small crystals, uniaxial and optically positive, with indices of 1.71 to 1.74 and high birefringence; porosity 37.7%; bulk density 2.015 g cm^{-3}; zero-point correction of 0.002% determined by graphical extrapolation.
4*	60	White, H.E. and Shremp, R.M.	1939	L	298-1273		Similar to the above specimen; bar fired to cone 33; porosity 31.7%; bulk density 2.142 g cm^{-3}; zero-point correction of 0.002% determined by graphical extrapolation.
5*	60	White, H.E. and Shremp, R.M.	1939	L	298-1273		Similar to the above specimen; electrically fused, refined to cone 33; crystal faces coated with iron oxide; index of 1.72 in thin section; zero-point correction of 0.002% determined by graphical extrapolation.
6	61	Grain, C.F. and Campbell, W.J.	1962	X	301-1405	hexagonal BeO	99+ pure; mixed with platinum powder, fired at 1500 C 12 hrs, cooled; spread on aluminum holder, fired at 1000 C 3 hrs; expansion measured along a-axis.
7	61	Grain, C.F. and Campbell, W.J.	1962	X	301-1405	hexagonal BeO	The above specimen; expansion measured along c-axis.
8	62	Miller, K.T.	1960	X	298-2323		Expansion measured along a-axis with CuKα radiation; lattice parameter at 25 C 2.6983 Å.
9	62	Miller, K.T.	1960	X	298-2323		The above specimen; expansion measured along c-axis; lattice parameter at 25 C 4.3742 Å.
10	63	Pears, C.D. and Oglesby, S.	1963	L	294-2458	Run E-21	Powdered specimen; initial length 3.031 in., final length 3.051 in.; obtained from Zirconium Corp. of America; pressed and sintered; density at 25 C, 2.93 g cm^{-3} by ASTM method B311-58; expansion measured in helium atm; reported error 5%.
11	63	Pears, C.D. and Oglesby, S.	1963	L	2458-294	Run E-21	The above specimen; expansion measured with decreasing temp; zero-point correction of -0.59%.
12	64	Hedge, J.C., Kostenko, C. and Lang, J.I.	1963	X	299-2233		99.5 BeO, 0.009 Si, 0.005 Al, 0.002 Mo, <0.001 each Fe, Ni, Cr, Ca, Na, trace B, Cd, Li, Co, Cu; cylindrical specimen, 1.27 cm dia, 15.24 cm long; obtained from Brush Beryllium Co; cold pressed and fired at 1582 C; density 2.87 g cm^{-3}; heating rate 2.5 to 3 C per min; expansion measured in argon atm; reported error 2%.
13	13	Gardner, W.J., McClelland, J.D. and Richardson, J.H.	1963	L	473-1273	Grade 1	99.5 pure; cylindrical translucent specimen; 0.63 cm dia, 5.08 cm long; obtained from Beryllium Corp; blended, wet screened; heated to 1750 C for 10 min, pressure applied in increments of 300 psi until 4000 psi, maintained 4 hrs, cooled slowly; expansion measured in air atm.
14*	66	General Dynamic Corp.	1960		293-1272		Density 2.9 g cm^{-3}.

*Not shown in figure.

SPECIFICATION TABLE 37. THERMAL LINEAR EXPANSION OF BERYLLIUM OXIDE BeO (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
15	67	Seibel, R.D. and Mason, G.L.	1958	L	699-1755		Specimen grain size < 0.001 in.; obtained from Beryllium Corp; density 1.74-2.16 g cm^{-3}; heating rate 2-5 C per min; expansion measured in vacuum 10^{-6}-10^{-5} mm Hg.
16	68	Klein, D.J.	1958	X	293-2313		Polycrystalline fine-grained specimen; supplied by Commissariat al' Energie Atomique, Sarclay, France; hot pressed in graphite molds; expansion measured along a-axis.
17	68	Klein, D.J.	1958	X	293-2058		The above specimen; expansion measured along c-axis.
18	17	Lukin, E.S. and Poluboyarinov, D.N.	1963	L	293-2273	Body 15	99.9 pure; specimen 4 x 4 x 20 mm; prepared from precalcined (1800 C) and chemically pure beryllia; pressed at 1000 g cm^{-2}, and fired at 1950 C; bulk density 2.84 g cm^{-3}; apparent porosity 0.0%; expansion measured in vacuum furnace; heating rate 5-8 C per min.
19	~~19~~	Engberg, C.J. and Zehms, E.H.	1958	T	308-2158	EP 1-2 s.p. grade	Specimen obtained from Oak Ridge; hot pressed; sintered at 2273 K during test; density 2.74 g cm^{-3}; expansion measured in argon atm.
20	70	Engberg, C.J. and Zehms, E.H.	1958	T	2101-313	EP 1-2	The above specimen; expansion measured with decreasing temp; zero-point correction of 0.952% determined by graphical extrapolation.
21	70	Engberg, C.J. and Zehms, E.H.	1958	T	298-2138	EP 1-2	The above specimen; expansion measured with increasing temp on second test.
22	70	Engberg, C.J. and Zehms, E.H.	1958	T	300-2473	DQ-1 s.p. grade	Specimen obtained from Oak Ridge; hot pressed; density 2.94 g cm^{-3}; expansion measured in argon atm.
23	70	Engberg, C.J. and Zehms, E.H.	1958	T	2473-300	DQ-1 s.p. grade	The above specimen; expansion measured with decreasing temp.
24*	70	Engberg, C.J. and Zehms, E.H.	1958	T	293-2258	FF-1	Specimen slip cast and sintered in oxidizing atm at 2073 K; density 2.76 g cm^{-3}; expansion measured in argon atm.
25*	70	Engberg, C.J. and Zehms, E.H.	1958	T	1273-2273	EP 1-3 s.p. grade	Specimen obtained from Oak Ridge; hot pressed; density 2.74 g cm^{-3}; expansion measured in argon atm.
26*	71	Flight Propulsion Lab. General Electric Co., Cincinnati, Ohio	1963	L	298-1473	HPA-grade	Cylindrical specimen; comprised of crystallites of about 1000 Å dia; 2 in. long; grain size 20 μ; obtained from Brush Beryllium Co; prepared from basic acetate process; extruded, sintered, randomly oriented; density 2.90 g cm^{-3}.
27*	71	Flight Propulsion Lab. General Electric Co., Cincinnati, Ohio	1963	L	298-1473	HPA-MgO grade	0.0205 Fe, 0.018 Si, 0.0086 C, 0.0083 Al, 0.005 Ni, 0.0045 Cr; specimen 2 in. long; grain size 20 μ; randomly oriented; density 2.90 g cm^{-3}.
28*	71	Flight Propulsion Lab. General Electric Co., Cincinnati, Ohio	1963	L	298-1473	AOX-grade	0.0115 C, 0.011 Mg, 0.0103 Fe, 0.0083 Si, 0.008 Ca, 0.0033 Ni, 0.0025 Al, 0.0025 Na; specimen 2 in. long; extruded, sintered.
29*	71	Flight Propulsion Lab. General Electric Co., Cincinnati, Ohio	1963	L	298-1473	UOX-grade	0.024 Fe, 0.016 C, 0.013 Ca, 0.009 Si, 0.008 Mg, 0.005 Al, 0.0035 Ni, 0.0027 P, 0.0024 Cr, 0.0023 S, 0.002 Zn; specimen 2 in. long; grain size 20 μ; extruded, sintered, preferentially oriented; crystallites 600-1000 Å dia; density 2.90 g cm^{-3}.
30*	71	Flight Propulsion Lab. General Electric Co., Cincinnati, Ohio	1963	L	298-1473	UOX-MgO grade	Specimen with 0.5 MgO composition 0.0215 Fe, 0.015 Ca, 0.0125 C, 0.0095 Si, 0.006 S, 0.0045 Al; 2 in. long; grain size 20 μ; extruded, sintered, preferentially oriented; density 2.90 g cm^{-3}.

*Not shown in figure.

SPECIFICATION TABLE 37. THERMAL LINEAR EXPANSION OF BERYLLIUM OXIDE BeO (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
31*	72	Fulkerson, S.D.	1959	L	273-1473		French specimen; hot pressed; zero-point correction of -1.454% determined by graphical interpolation.
32	73	Baldock, P.Y., Spindler, W.E. and Baker, T.W.	1966	X	303-2071	BeO-12	0.134 $SO_4^=$, 0.013 Ca, 0.008 Si, < 0.005 Na, 0.0035 Al, 0.002 Mg, 0.0015 Fe, 0.0008 Li, 0.00003 B; specimen 3 x 6 x 32 mm; prepared from Milford Haven Sulphate Material by calcination at 1000 C; cold-pressed at 10 ton/in^2, water used as binder, sintered in air at 1700 C 3 hrs; expansion measured along a-axis; lattice parameter at 20 C 2.6991 Å.
33	73	Baldock, P.Y. et al.	1966	X	308-1773	BeO-12	The above specimen; expansion measured along c-axis; lattice parameter at 20 C 4.3776 Å.
34	73	Baldock, P.Y. et al.	1966	X	303-2320	BeO-13	Similar to the above specimen; expansion measured along a-axis.
35	73	Baldock, P.Y. et al.	1966	X	308-2328	BeO-13	The above specimen; expansion measured along c-axis.
36	73	Baldock, P.Y. et al.	1966	X	773-2192	BeO-14	Similar to the above specimen; expansion measured along a-axis.
37	73	Baldock, P.Y. et al.	1966	X	773-2196	BeO-14	Similar to the above specimen; expansion measured along c-axis.
38*	74	Beals, R.J. and Cook, R.L.	1957	X	301-1473		Reagent grade, hexagonal structured powder specimen.
39*	75	Fryxell, R.E. and Chandler, B.A.	1964	L	298-1473	Specimen 3	Cylindrical specimen; 35% preferential c-axis grain orientation; zero-point correction of 0.002% determined by graphical extrapolation.
40*	75	Fryxell, R.E. and Chandler, B.A.	1964	L	298-1473	Specimen 2	Similar to the above specimen; except 52% grain orientation; zero-point correction of 0.002% determined by graphical extrapolation.
41*	75	Fryxell, R.E. and Chandler, B.A.	1964	L	298-1473	Specimen 1	Similar to the above specimen; except 72% grain orientation; zero-point correction of 0.003% determined by graphical extrapolation.
42*	75	Fryxell, R.E. and Chandler, B.A.	1964	L	298-1473	Specimen 5	Similar to the above specimen; except 73% grain orientation; zero-point correction of 0.002% determined by graphical extrapolation.
43*	75	Fryxell, R.E. and Chandler, B.A.	1964	L	298-1473	Specimen 7	Similar to the above specimen; except 79% grain orientation; zero-point correction of 0.003% determined by graphical extrapolation.
44*	75	Fryxell, R.E. and Chandler, B.A.	1964	L	298-1473	Specimen 6	Similar to the above specimen; except 80% grain orientation; zero-point correction of 0.002% determined by graphical extrapolation.
45*	75	Fryxell, R.E. and Chandler, B.A.	1964	L	298-1473	Specimen 4	Similar to the above specimen; except 82% grain orientation; zero-point correction of 0.003% determined by graphical extrapolation.
46*	76	Flight Propulsion Lab. General Electric Co., Cincinnati, Ohio	1962	L	298-1473	AOX-grade	Specimen grain size 5-100 μ; As-sintered; randomly oriented.
47*	76	Flight Propulsion Lab. General Electric Co., Cincinnati, Ohio	1962	L	298-1473	HPA-grade	Specimen grain size 20 μ; As-sintered; randomly oriented; high density.
48*	76	Flight Propulsion Lab. General Electric Co., Cincinnati, Ohio	1962	L	298-1473	HPA-MgO grade	Specimen grain size 5-80 μ; As-sintered; randomly oriented.
49*	76	Flight Propulsion Lab. General Electric Co., Cincinnati, Ohio	1962	L	298-1473	UOX-grade	Specimen grain size 20 μ; As-sintered; preferentially oriented; high density.

*Not shown in figure.

SPECIFICATION TABLE 37. THERMAL LINEAR EXPANSION OF BERYLLIUM OXIDE BeO (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
50*	76	Flight Propulsion Lab. General Electric Co., Cincinnati, Ohio	1962	L	298-1473	UOX-MgO grade	Specimen grain size 20 μ; As-sintered; preferentially oriented; high density.
51*	76	Flight Propulsion Lab. General Electric Co., Cincinnati, Ohio	1962	L	298-1473	UOX-ZrO_2 grade	Specimen grain size 20 μ; As-sintered; preferentially oriented; high density.
52*	77	Schwartz, B.	1952	L	273-1273		Cylindrical specimen; 1.27 cm dia, 3.76 cm long.
53*	78	General Electric Co.-NMPO Cincinnati, Ohio	1963	L	79-299	AOX grade	Specimen 3.5 in. long; grain size 100 μ.
54*	78	General Electric Co.-NMPO Cincinnati, Ohio	1963	L	307-1472	AOX grade	Similar to the above specimen; direct measurements made with traveling cathetometer of two small holes drilled 2 in. apart through specimen; temp accurate to ±10 C.
55*	79	Taylor, R.E.	1960	L	293-1370		Specimen hot pressed; sintered at 1173 K; density 1.50 g cm^{-3}.
56*	79	Taylor, R.E.	1960	L	293-1273		Similar to the above specimen; density 2.89 g cm^{-3}.
57*	32	Filippi, F.J.	1963	L	317-1134	Specimen 1	99.7 pure; specimen 2 in. long; obtained from Beryllium Corporation's Berylco.
58*	32	Filippi, F.J.	1963	L	315-978	Specimen 2	Similar to the above specimen.
59*	81	General Electric Co.-NMPO Cincinnati, Ohio	1964	L	293-1446	AOX-grade	No details given.
60*	82	Rossi. R.C.	1969	L	293,1273		Specimen hot pressed at more than 4000 psi, 1773 K; 76.1% of theoretical density.
61*	82	Rossi, R.C.	1969	L	293,1273		Similar to the above specimen; 91.4% of theoretical density.
62*	82	Rossi, R.C.	1969	L	293,1273		Similar to the above specimen; 97.7% of theoretical density.
63	83	Kirchner, H.P. and Gruver, R.M.	1967	X	293-1275		Expansion measured along a-axis.
64	83	Kirchner, H.P. and Gruver, R.M.	1967	X	293-1275		Expansion measured along c-axis.
65*	213	McCreight, L.R.	1952	I	293-693		Three conical shaped specimens 4 mm in height and diameter; sintered or compacted to give strength; argon atmosphere; zero-point correction is -0.03%.
66	642	Taylor, R.E.	1962	L/T	1144-2361	Specimen 3500	Powder specimen; obtained from Fairmount Chemical Co., Inc., N.Y.; density 2.99 g cm^{-3}; hot-pressed at 1973 K; commercial dilatometer used from room temperature to 1373 K for specimens in the form of bars 1/8 x 1/8 x 2 in.; above 1073 K telescopes used by observing relative displacement of fiducial marks on opposite ends of specimens 1/4 x 1/4 x 5 in. long as they heated in graphite tube furnace and protect them from contamination in argon atmosphere at 50 psig pressure.
67	642	Taylor, R.E.	1962	L/T	1423-2309	Specimen 3501	Similar to the above specimen except density 2.98 g cm^{-3}.
68*	642	Taylor, R.E.	1962	L/T	473-1273	Specimens 29164, 29171, 29182, 18066, 18053	Similar to the above specimen; averaged values of five different specimens; specimen 29164 obtained from Brush Beryllium Co.; density 2.91 g cm^{-3}; hot-pressed at 1973 K; specimen 29171 obtained from Fairmount Chemical Co., Inc., N.Y.; density 2.89 g cm^{-3}; hot-pressed at 1973 K; specimen 29182 same as specimen 29171 except density 2.91 g cm^{-3}; specimen 18066 obtained from Brush Beryllium Co.; density 2.43 g cm^{-3}; isostatically pressed, slight sintering at 1273 K; specimen 18053 same as specimen 18066 except density 2.74 g cm^{-3} and isostatically pressed only.

*Not shown in figure.

DATA TABLE 37. THERMAL LINEAR EXPANSION OF BERYLLIUM OXIDE BeO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
292	0.000
353	0.042
419	0.085
477	0.127
566	0.196
643	0.264
725	0.336
798	0.404
868	0.475
1021	0.635
1139	0.766
1204	0.839
1272	0.915
CURVE 2*	
866	0.526
CURVE 3	
298	0.002
323	0.014
373	0.042
423	0.074
473	0.109
523	0.147
573	0.185
623	0.226
673	0.272
723	0.311
773	0.354
823	0.402
873	0.452
923	0.499
973	0.551
1023	0.601
1073	0.655
1123	0.710
1173	0.759
1223	0.813
1273	0.869
CURVE 4*	
298	0.002
323	0.014

T	$\Delta L/L_0$
CURVE 4 (cont.)	
373	0.042
423	0.072
473	0.107
523	0.146
573	0.184
623	0.224
673	0.268
723	0.309
773	0.353
823	0.399
873	0.447
923	0.494
973	0.544
1023	0.597
1073	0.652
1123	0.710
1173	0.759
1223	0.808
1273	0.868
CURVE 5*	
298	0.002
323	0.014
373	0.042
423	0.072
473	0.107
523	0.144
573	0.182
623	0.222
673	0.266
723	0.308
773	0.352
823	0.396
873	0.443
923	0.489
973	0.545
1023	0.589
1073	0.639
1123	0.694
1173	0.752
1223	0.807
1273	0.863

T	$\Delta L/L_0$
CURVE 6	
301	0.00
525	0.16
747	0.35
1022	0.61
1145	0.78
1405	1.09
CURVE 7	
301	0.00
525	0.14
747	0.30
1022	0.56
1145	0.69
1405	0.98
CURVE 8	
298	0.00
1488	1.16
1585	1.26
1603	1.39
1723	1.50
1823	1.67
1881	1.74
1981	1.90
2323	2.27
CURVE 9	
298	0.00
1488	1.09
1585	1.19
1603	1.34
1723	1.48
1823	1.59
1881	1.65
1981	1.84
2323	2.56
CURVE 10	
294	0.00*
538	0.15
859	0.42
1109	0.64

T	$\Delta L/L_0$
CURVE 10 (cont.)	
1130	0.64
1319	0.84
1622	1.15
1888	1.49
2091	1.64
2110	1.64
2144	1.63
2255	1.65
2394	1.82
2408	2.24
2458	2.99
2458	3.01*
CURVE 11	
2458	2.42
2060	1.69
1674	1.25
1352	0.89
1337	0.89
983	0.52
670	0.26
466	0.08
294	0.00*
CURVE 12	
299	0.005*
402	0.081
541	0.182
635	0.255
730	0.325
874	0.462*
1024	0.617*
1185	0.795
1252	0.876
1380	1.047
1445	1.138
1519	1.238
1619	1.344
1710	1.462
1813	1.615
1972	1.767
2144	1.996
2233	2.092

T	$\Delta L/L_0$
CURVE 13‡	
473	0.097
673	0.204
873	0.342
1073	0.497
1273	0.662
CURVE 14*	
293	0.000
373	0.044
572	0.220
872	0.551
1272	1.056
CURVE 15	
699	0.361
755	0.412
810	0.466
866	0.522
922	0.576
977	0.635
1033	0.689
1088	0.750
1144	0.810
1199	0.861
1255	0.934
1310	1.000
1366	1.065
1422	1.145
1477	1.210
1533	1.270
1588	1.360
1644	1.440
1699	1.500
1755	1.560
CURVE 16	
293	0.000*
373	0.060
547	0.180
648	0.223
738	0.360
798	0.357
868	0.480

T	$\Delta L/L_0$
CURVE 16 (cont.)	
920	0.477
976	0.492
1023	0.588
1082	0.632
1173	0.729
1242	0.828
1350	0.945
1446	1.105
1559	1.258
1673	1.260
1684	1.415
1777	1.515
2046	1.702
2168	1.830
2313	1.890
CURVE 17	
293	0.000*
383	0.029
553	0.147
658	0.205
743	0.320
805	0.332
873	0.417
928	0.388
978	0.490
1028	0.560
1088	0.596
1178	0.691
1253	0.797
1353	0.902
1448	1.043
1561	1.125
1678	1.158
1688	1.284
1779	1.457
2058	1.616
CURVE 18	
293	0.000*
1273	0.911*
1373	1.037
1473	1.192
1573	1.306

* Not shown in figure.

‡ Author's data for coefficient of expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 37. THERMAL LINEAR EXPANSION OF BERYLLIUM OXIDE BeO (continued)

T	$\Delta L/L_0$
CURVE 18 (cont.)	
1673	1.421
1773	1.584
1873	1.691
1973	1.814
2073	1.931
2173	2.050
2273	2.170
CURVE 19	
308	0.003
1183	0.823
1298	0.943
1373	1.043*
1483	1.133
1603	1.283
1673	1.373
1788	1.523
1898	1.733
2018	1.913
2103	1.953
2158	2.023
CURVE 20	
2101	1.955
2009	1.895
1921	1.865
1757	1.455
1593	1.235
1469	1.095
1369	1.005
1285	0.893
313	0.005*
CURVE 21	
298	0.00*
1123	0.80
1233	0.88
1283	0.98
1353	1.07
1475	1.21*
1573	1.35
1633	1.44
1728	1.58
1808	1.73
1913	1.86

T	$\Delta L/L_0$
CURVE 21 (cont.)	
1998	1.97
2043	2.05
2123	2.20
2138	2.33
CURVE 22	
300	0.00*
1178	0.78*
1273	0.90*
1428	1.05
1548	1.17
1580	1.22
1683	1.36
1828	1.53
1938	1.67
2113	1.89
2208	1.99
2271	2.05
2343	2.10
2388	2.42
2423	2.60
2453	2.79
2473	2.85
CURVE 23	
2473	2.98
2448	2.90
2378	2.75
2308	2.60
2288	2.54
2258	2.42
2218	2.09
2093	1.94
2008	1.80
1823	1.59
1743	1.45
1623	1.32
1583	1.26
1513	1.17
1428	1.02
1273	0.86
1178	0.74
300	0.00*
CURVE 24*	
293	0.00

T	$\Delta L/L_0$
CURVE 24 (cont.)*	
1073	0.69
1158	0.79
1258	0.94
1348	1.06
1448	1.18
1538	1.31
1658	1.42
1728	1.56
1828	1.67
1938	1.84
2043	1.99
2123	2.06
2233	2.20
2258	2.24
CURVE 25*	
1273	0.88
1473	1.14
1673	1.40
1873	1.66
2073	1.84
2273	1.79
CURVE 26*	
298	0.004
873	0.455
1073	0.651
1273	0.867
1473	1.101
CURVE 27*	
298	0.004
873	0.458
1073	0.656
1273	0.873
1473	1.114
CURVE 28*	
298	0.004
873	0.456
1073	0.659
1273	0.879
1473	1.114

T	$\Delta L/L_0$
CURVE 29*	
298	0.004
873	0.441
1073	0.632
1273	0.843
1473	1.073
CURVE 30*	
298	0.004
873	0.444
1073	0.638
1273	0.848
1473	1.079
CURVE 31*	
273	-0.014
473	0.134
673	0.298
873	0.476
1073	0.677
1273	0.899
1473	1.136
CURVE 32	
303	0.004*
483	0.182
622	0.263
799	0.474
1021	0.685
1257	1.008
1463	1.197
1773	1.575
2071	1.982
CURVE 33	
308	-0.002*
488	0.142
621	0.228
797	0.418
1020	0.619
1256	0.886
1466	1.089
1773	1.467

T	$\Delta L/L_0$
CURVE 34	
303	0.007*
721	0.393
928	0.593
1162	0.834
1377	1.123
1662	1.423
2053	2.001
2096	2.082
2323	2.367
CURVE 35	
308	0.034
721	0.340
927	0.512
1163	0.779
1378	1.030
1662	1.302
2052	1.841
2101	1.912
2328	2.204
CURVE 36	
773	0.404
1286	0.908
1329	1.023
1556	1.326
1927	1.775
2075	2.027
2192	2.127
CURVE 37	
773	0.361
1281	0.816
1327	0.932
1558	1.236
1935	1.636
2080	1.855
2196	1.946
CURVE 38*	
301	0.000
473	0.145
673	0.311
873	0.486

T	$\Delta L/L_0$
CURVE 38 (cont.)*	
1073	0.666
1273	0.856
1473	1.069
CURVE 39*	
298	0.002
573	0.179
873	0.444
1073	0.638
1273	0.849
1473	1.085
CURVE 40*	
298	0.002
573	0.181
873	0.438
1073	0.632
1273	0.841
1473	1.071
CURVE 41*	
298	0.003
573	0.177
873	0.432
1073	0.616
1273	0.820
1473	1.046
CURVE 42*	
298	0.002
573	0.173
873	0.424
1073	0.611
1273	0.821
1473	1.050
CURVE 43*	
298	0.003
573	0.181
873	0.431
1073	0.617
1273	0.822
1473	1.045

* Not shown in figure.

DATA TABLE 37. THERMAL LINEAR EXPANSION OF BERYLLIUM OXIDE BeO (continued)

T	$\Delta L/L_0$
CURVE 44*	
298	0.002
573	0.180
873	0.428
1073	0.613
1273	0.817
1473	1.044
CURVE 45*	
298	0.003
573	0.182
873	0.431
1073	0.615
1273	0.821
1473	1.044
CURVE 46*	
298	0.000
573	0.181
873	0.453
1073	0.652
1273	0.871
1473	1.110
CURVE 47*	
298	0.000
573	0.181
873	0.452
1073	0.651
1273	0.868
1473	1.105
CURVE 48*	
298	0.000
573	0.181
873	0.454
1073	0.656
1273	0.874
1473	1.115
CURVE 49*	
298	0.000
573	0.173
873	0.432

T	$\Delta L/L_0$
CURVE 49 (cont.)*	
1073	0.622
1273	0.831
1473	1.062
CURVE 50*	
298	0.000
573	0.176
873	0.439
1073	0.633
1273	0.844
1473	1.076
CURVE 51*	
298	0.000
573	0.176
873	0.434
1073	0.624
1273	0.834
1473	1.062
CURVE 52*	
273	-0.010
373	0.042
473	0.099
573	0.169
673	0.252
773	0.339
873	0.431
973	0.526
1073	0.619
1173	0.716
1273	0.814
CURVE 53*	
79	-0.0412
188	-0.0335
233	-0.0236
299	0.0014
CURVE 54*	
307	0.010
519	0.161
773	0.378

T	$\Delta L/L_0$
CURVE 54 (cont.)*	
1022	0.630
1273	0.895
1472	1.120
CURVE 55*	
293	0.000
373	0.055
473	0.117
573	0.201
673	0.271
774	0.378
873	0.477
974	0.576
1073	0.679
1173	0.778
1273	0.856
1370	0.973
CURVE 56*	
293	0.000
373	0.036
473	0.108
573	0.195
673	0.280
773	0.369
873	0.458
973	0.558
1073	0.662
1173	0.764
1273	0.866
CURVE 57*	
317	0.009
322	0.012
355	0.025
409	0.052
489	0.101
560	0.152
645	0.226
733	0.301
791	0.367
841	0.399
863	0.435
908	0.471
940	0.504

T	$\Delta L/L_0$
CURVE 57 (cont.)*	
984	0.536
1021	0.582
1061	0.627
1107	0.671
1134	0.712
CURVE 58*	
315	0.006
322	0.008
353	0.021
394	0.044
438	0.068
476	0.095
516	0.124
560	0.160
601	0.188
644	0.225
685	0.258
719	0.294
774	0.337
818	0.380
862	0.438
911	0.484
953	0.522
978	0.556
CURVE 59*	
293	0.000
873	0.457
1073	0.650
1273	0.868
1446	1.093
CURVE 60*	
1273	0.853
CURVE 61*	
1273	0.843
CURVE 62*	
1273	0.853

T	$\Delta L/L_0$
CURVE 63	
293	0.000*
473	0.122
673	0.287
873	0.480*
1073	0.705
1275	0.914
CURVE 64	
293	0.000*
473	0.107
673	0.258
873	0.433
1073	0.636
1275	0.814
CURVE 65*	
293	0.00
333	0.03
363	0.06
393	0.08
423	0.11
453	0.14
483	0.17
513	0.19
543	0.22
573	0.25
603	0.28
633	0.30
663	0.33
693	0.36
CURVE 66	
1144	0.71
1302	0.85
1437	1.04
1573	1.18
1694	1.34
1847	1.56
2065	1.87
2213	2.07
2347	2.38
2361	2.59
2361	3.05

T	$\Delta L/L_0$
CURVE 67	
1425	1.07*
1482	1.16*
1701	1.42
2061	1.83
2273	2.14
2278	2.20
2309	2.24
CURVE 68*	
473	0.11
673	0.27
873	0.46
1073	0.65
1273	0.87

* Not shown in figure.

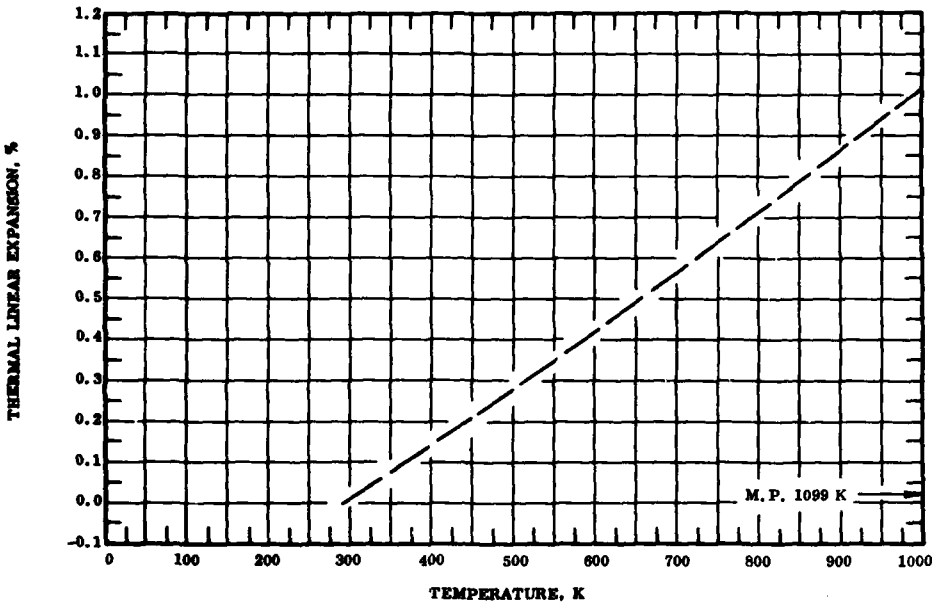
DATA TABLE 37. COEFFICIENT OF THERMAL LINEAR EXPANSION OF BERYLLIUM OXIDE BeO

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 13*, ‡	
473	4.39
673	6.35
873	7.45
1073	8.01
1273	8.57

* No figure given.
‡ Author's data for coefficient of expansion have been integrated by TPRC to obtain $\Delta L/L_o$.

FIGURE AND TABLE NO. 38R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF CADMIUM OXIDE CdO



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	13.2
350	0.076	13.4
400	0.143	13.5
450	0.211	13.7
500	0.279	13.8
550	0.349	14.0
600	0.419	14.1
650	0.490	14.3
700	0.562	14.5
750	0.635	14.6
800	0.709	14.8
850	0.783	15.0
900	0.859	15.2
950	0.935	15.3
1000	1.012	15.5

REMARKS

The provisional values are based on the data measured by x-ray method (curve 1) and are considered accurate to within ±7%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.374 + 1.234 \times 10^{-3}\ T + 1.360 \times 10^{-7}\ T^2 + 1.542 \times 10^{-11}\ T^3$$

The tabulated values for the coefficient of thermal expansion are based on the experimental data and are considered accurate to about ±7%.

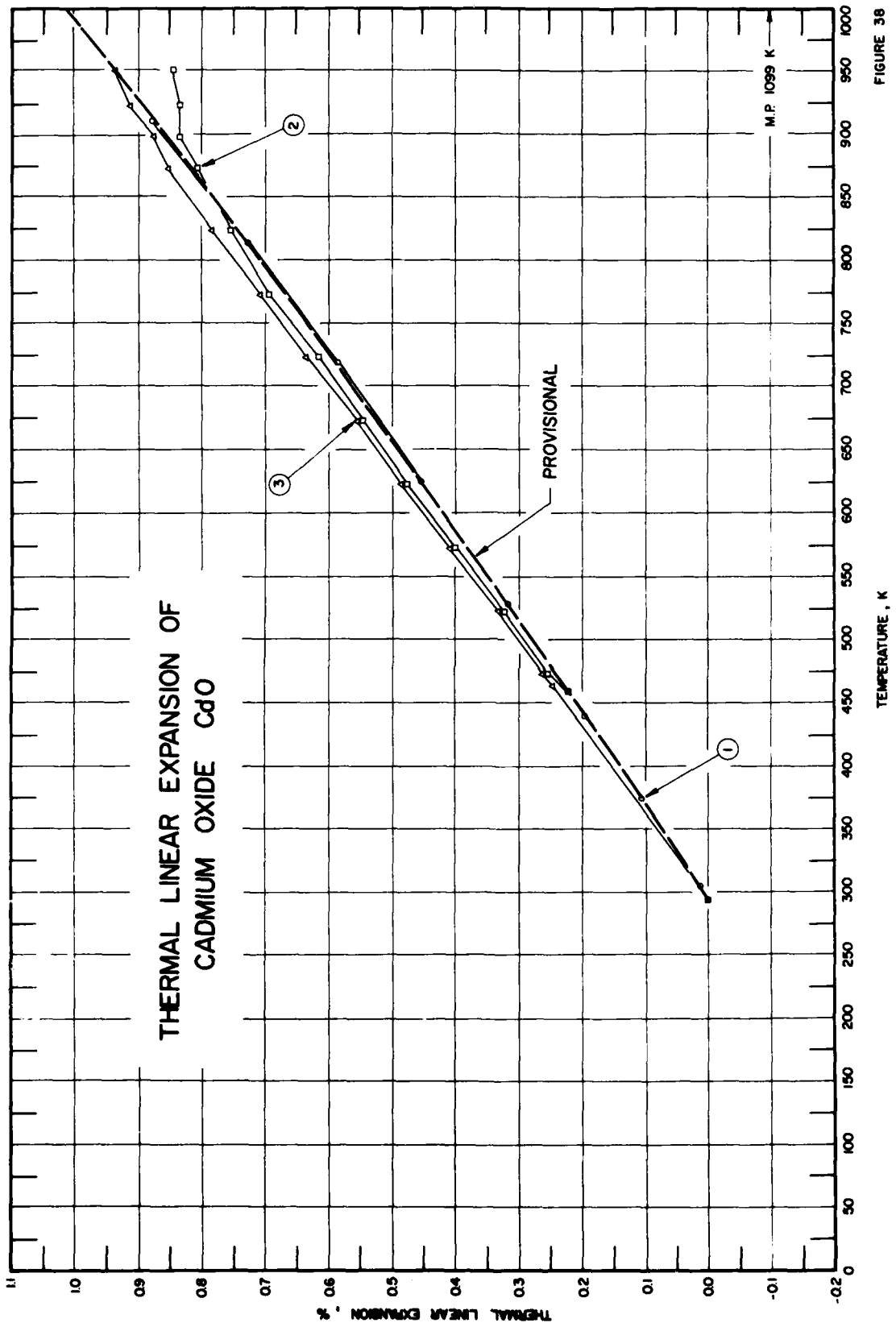

THERMAL LINEAR EXPANSION OF
CADMIUM OXIDE CdO
PROVISIONAL
M.P. 1099 K
1
2
3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 38

SPECIFICATION TABLE 38. THERMAL LINEAR EXPANSION OF CADMIUM OXIDE CdO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	65	Singh, H.P. and Dayal, B.	1969	X	305-1005		Specimen obtained by crushing analar CdO into fine powder, sieving through 200 mesh screen, introduced into fine quartz capillary of 0.3 mm I.D., annealed at 625 K for 4 hr; expansion measured along a-axis; lattice parameter reported at 305.2 K is 4.6957 Å; 4.6950 Å at 293.2 K determined by graphical extrapolation; coefficient of thermal linear expansion also reported.
2	586	Valeev, Kh.S. and Kvaskov, V.B.	1971	L	293-948		Error < 1% for elongation and ± 2 C for temperature specimen obtained by roasting for 1.5 to 2 hr in air pressed powders (Ar grade) at 680-700 C, sintered polycrystalline material structure: hfc, Δt: 20-500 C, heating rate 10° per min.; zero-point correction is 0.019%.
3	586	Valeev, Kh.S. and Kvaskov, V.B.	1971	L	293-948		Similar to the above specimen; zero-point correction is 0.063%.

DATA TABLE 38. THERMAL LINEAR EXPANSION OF CADMIUM OXIDE CdO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 2 (cont.)		CURVE 3 (cont.)		CURVE 3 (cont.)	
305	0.0149	293	0.000	823	0.755	463	0.248	873	0.852
376	0.1086	459	0.223	873	0.808	473	0.267	898	0.878
440	0.1980	473	0.254	898	0.834	523	0.333	923	0.914
529	0.3194	523	0.323	923	0.834	573	0.408	948	0.938
625	0.4568	573	0.400	948	0.845	623	0.485		
718	0.5878	623	0.477			673	0.558		
814	0.7263	673	0.550	CURVE 3		723	0.637		
911	0.8796	723	0.614			773	0.708		
1005	1.0181*	773	0.693	293	0.000*	823	0.782		

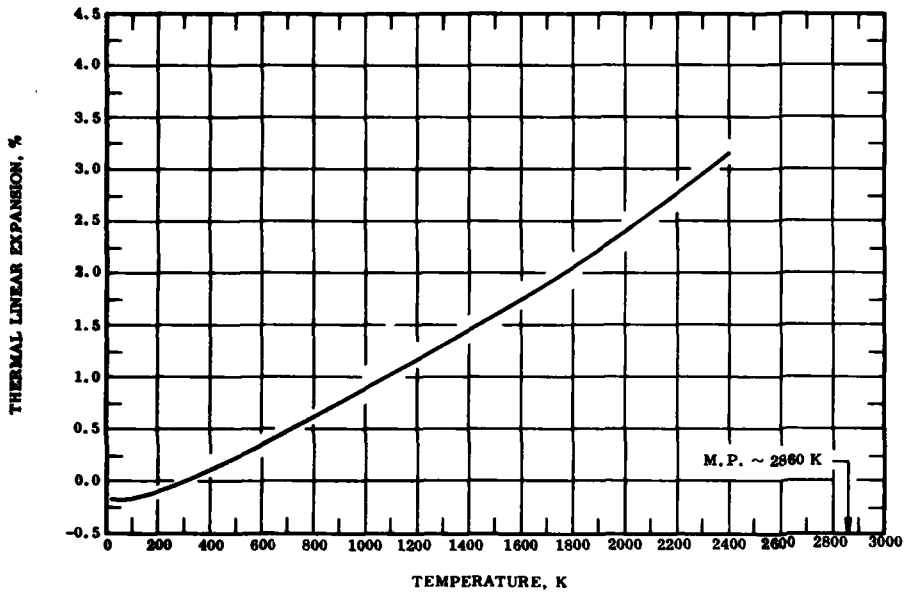
DATA TABLE 38. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CADMIUM OXIDE CdO

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α
CURVE 1*		CURVE 1 (cont.)*	
305	13.31	625	14.23
376	13.50	718	14.53
440	13.68	814	14.85
529	13.94	911	15.20
		1005	15.54

* Not shown in figure.

FIGURE AND TABLE NO. 39R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF CALCIUM OXIDE CaO



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
20	-0.166	0.0
40	-0.164	0.5
60	-0.163	1.7
80	-0.159	2.8
100	-0.153	3.8
150	-0.127	6.2
200	-0.091	8.3
250	-0.045	10.0
293	0.000	11.2
400	0.123	11.7
600	0.363	12.3
800	0.616	13.0
1000	0.882	13.6
1200	1.161	14.3
1400	1.456	15.1
1600	1.766	15.9
1800	2.090	16.7
2000	2.432	17.5
2200	2.790	18.4
2400	3.178	19.3

REMARKS

The recommended values are based on the data for pure samples (curves 4, 11, 15 and 16) and are considered accurate to within ±5%. These values are represented approximately by the following equations:

$$\Delta L/L_0 = -0.163 - 2.035 \times 10^{-4}\, T + 3.299 \times 10^{-6}\, T^2 - 2.385 \times 10^{-9}\, T^3 \qquad (20\text{–}293\ K)$$

$$\Delta L/L_0 = -0.321 + 1.059 \times 10^{-3}\, T + 1.310 \times 10^{-7}\, T^2 + 1.405 \times 10^{-11}\, T^3 \qquad (293\text{–}2400\ K)$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±7%.

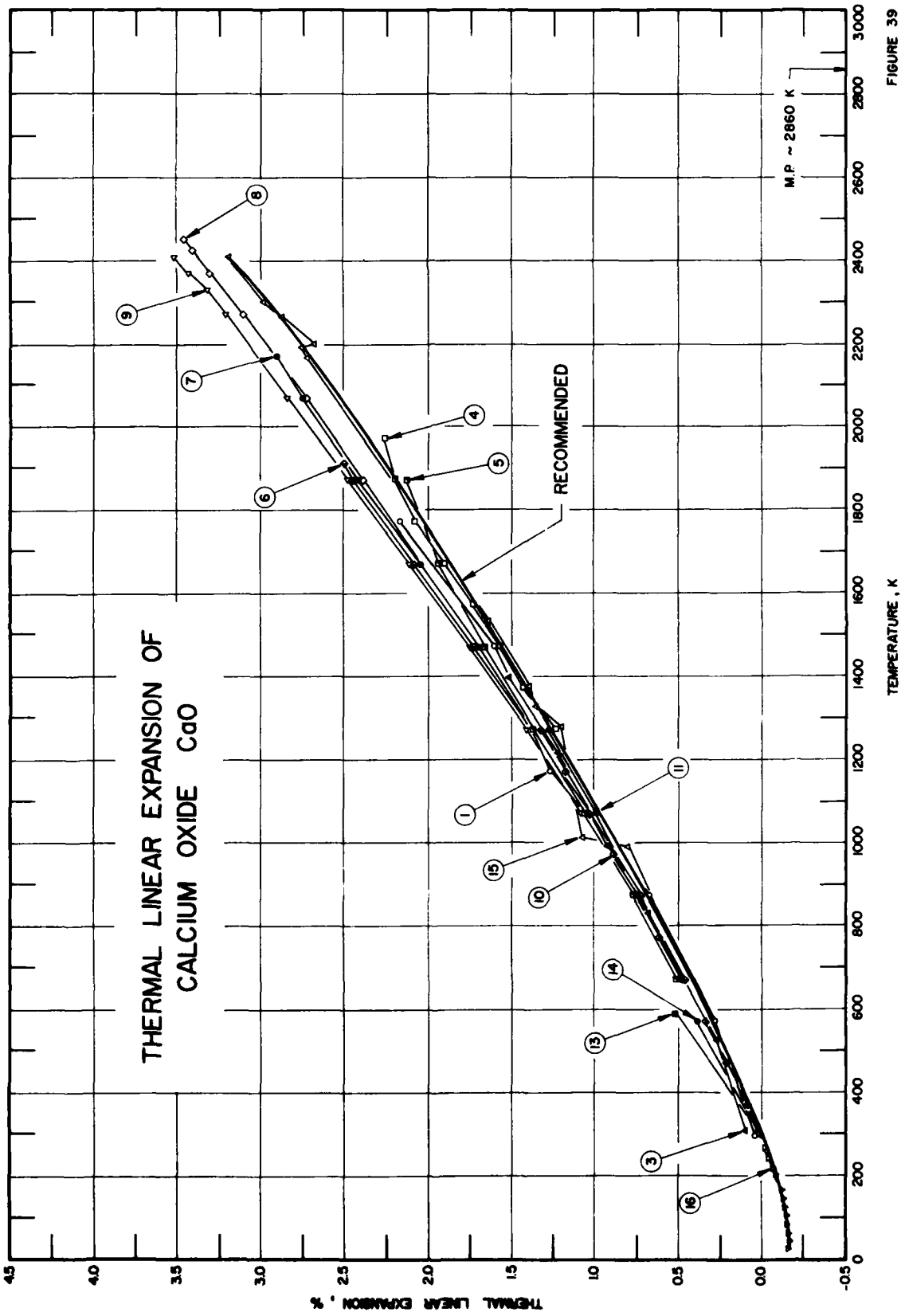

THERMAL LINEAR EXPANSION OF
CALCIUM OXIDE CaO
RECOMMENDED
M.P. ~ 2860 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
1
2
3
4
5
6
7
8
9
10
11
13
14
15
16

FIGURE 39

SPECIFICATION TABLE 39. THERMAL LINEAR EXPANSION OF CALCIUM OXIDE CaO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1	Whittemore, O.J., Jr.	1956	T	298-1773		Specimen 1.27 cm square, 17.78 cm long; coarse fused grain; ends sawed at rake and to point; zero-point correction of 0.005% determined by graphical extrapolation.
2*	69	Finlay, G.R.	1952		293,1073		Density 3.37 g cm^{-3}.
3	61	Grain, C.F. and Campbell, W.J.	1962	X	302-1398		Reagent quality specimen; mixed with 40% Pt; fired in air at 1673 K for 5 hrs, cooled under desication, spread on platinum-coated alumina holder; zero-point correction of 0.01% determined by graphical extrapolation.
4		Lukin, E.S. and Serova, G.A.	1964	L	1273-1973		Specimen prepared from chemically pure $CaCO_3$, fired at 1623-1673 K, ground for 5 hrs in steel ball mill to grain size of 1-2μ, pressed at 1000 kg cm^{-2}, and fired at 2023 K for 2 hrs; expansion measured in vacuum.
5	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-1873	HP 105	99.5+ pure; specimen 3 in. long; grain size 57±9μ; obtained from Mallinckrodt primary std.; vacuum-calcined at 1043 K at 28 in. Hg; hot-pressed 4000 psi, 1450 C for 30 min; expansion measured in air atmosphere.
6	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-1873	HP 105	The above specimen; expansion measured with decreasing temperature.
7	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-2173	HP 105	The above specimen, final grain size 80-1200μ; expansion measured with increasing temperature on second test.
8	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-2450	HP 105	The above specimen, final grain size 100-1500μ; 97.8% theoretical density; expansion measured with increasing temperature on third test.
9	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-2403	LA-7	0.2 total impurities; specimen 3 in. long; grain size 111±13μ; supplied by New England Lime Co.; briquetted and fired at 2023 K; 0.5 hrs soak in reducing atmosphere; pulverized; milled 20 hrs; slip cast; fired at 1923 K, 10 hrs soak; 96.3% theoretical density; expansion measured in air atmosphere.
10	154	Rigby, G.R. and Green, A.T.	1941	L	373-1473	Lime	No details given; zero-point correction of 0.093% determined by graphical extrapolation.
11	74	Beals, R.J. and Cook, R.L.	1957	X	301-1473		Reagent grade specimen, cubic structured powder; zero-point correction of 0.011% determined by graphical extrapolation.
12*	88	Ohba, H., Hiragushi, K. and Nakashima, C.	1965	X	1073-1773		Specimen prepared by the composed products of Dolomite; expansion measured along d(200) in air atmosphere; 2.406 Å at 293 K used for data conversion.
13	89	Rice, R.W.	1969	V	311,593		Single crystal specimen, 0.75 in. long; purchased from Semi-Elements, Saxonburg, Pa.; expansion measured along <100> direction.
14	89	Rice, R.W.	1969	V	311,593		Polycrystalline; specimen made with LiF, then fired to 1373 K.
15	588	Kamada, O., Takizawa, T., and Sakurai, T.	1970	X	293-2406		Sintered specimen, guaranteed grade, slab 35 x 35 x 10 mm^3 whose surface was ground plane, heated by irradiation; zero-point correction is -0.05%.
16	587	Smith, D.K. and Leider, H.R.	1968	X	21-299		Specimen from Semi-Elements Inc., 99.92 CaO, 0.001 Al, 0.0001 Fe, 0.03 Mg, 0.0025 Si, 0.05 Sn; in the form of (100) plates cleaved from large crystals of 0.05 cm thick; error range ±0.002 Å.

*Not shown in figure.

DATA TABLE 39. THERMAL LINEAR EXPANSION OF CALCIUM OXIDE CaO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.005
573	0.286
873	0.673
1173	1.126
1473	1.617
1773	2.176
CURVE 2*	
293	0.000
1073	1.092
CURVE 3	
302	0.01
528	0.27
823	0.68
995	0.92
1218	1.23
1398	1.53
CURVE 4	
1273	1.24
1373	1.43
1473	1.58
1573	1.74
1673	1.90
1773	2.08
1873	2.20
1973	2.26
CURVE 5	
673	0.502
873	0.766
1073	1.006
1273	1.356
1473	1.653
1673	1.947
1873	2.237
CURVE 6	
1906	2.500
1873	2.474
1673	2.085

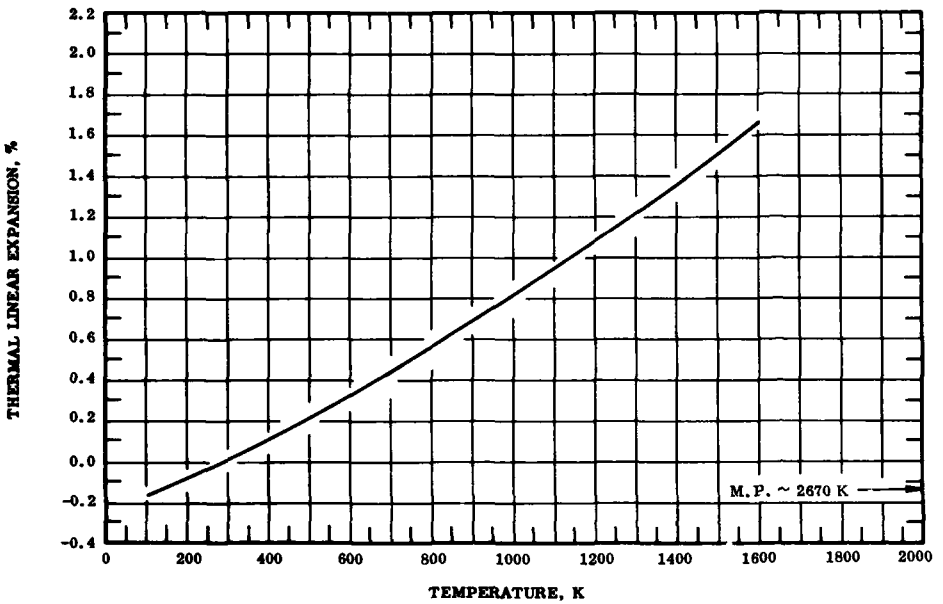
T	$\Delta L/L_0$
CURVE 6 (cont.)	
1473	1.707
1273	1.356*
1073	1.038
873	0.731
673	0.456
CURVE 7	
673	0.472
873	0.750
1073	1.053*
1273	1.373*
1473	1.700
1673	2.049
1873	2.414
2073	2.752
2173	2.910
CURVE 8	
673	0.461*
873	0.734*
1073	1.034*
1273	1.356*
1473	1.682*
1673	2.036*
1873	2.392
2073	2.747
2273	3.117
2373	3.309
2423	3.404
2450	3.464
CURVE 9	
673	0.476*
873	0.763*
1073	1.073
1273	1.400
1473	1.750
1673	2.111
1873	2.480
2073	2.850
2273	3.223
2328	3.330
2377	3.443
2403	3.515

T	$\Delta L/L_0$
CURVE 10	
373	0.093
473	0.217
573	0.343
673	0.474*
773	0.609
873	0.744*
973	0.893
1073	1.040*
1173	1.184
1273	1.313
1373	1.443*
1473	1.589*
CURVE 11	
301	0.011
473	0.244*
673	0.496*
873	0.746*
1073	1.007
1273	1.287
1473	1.604*
CURVE 12*	
1073	0.998
1173	1.122
1273	1.288
1373	1.455
1473	1.579
1573	1.704
1673	1.829
1773	2.037
CURVE 13	
311	0.030*
593	0.501
CURVE 14	
311	0.024*
593	0.396

T	$\Delta L/L_0$
CURVE 15	
293	0.00
990	0.80
1015	1.07
1279	1.20
1325	1.35
1376	1.38
1467	1.59*
1534	1.64
2162	2.73
2193	2.77
2200	2.69
2261	2.88
2301	2.99
2406	3.21
CURVE 16	
21	-0.160
26	-0.173*
35	-0.173*
42	-0.173
60	-0.164
80	-0.154
90	-0.152*
101	-0.152
112	-0.139*
122	-0.141
143	-0.135
153	-0.121*
164	-0.123
166	-0.123*
170	-0.121*
201	-0.087
218	-0.075*
219	-0.069
244	-0.046
266	-0.025
275	-0.015*
287	-0.006*
293	0.000*
299	0.004*

*Not shown in figure.

FIGURE AND TABLE NO. 40R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF CERIUM DIOXIDE CeO_2



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
100	-0.170	8.2
200	-0.085	8.9
293	0.000	9.5
400	0.106	10.2
500	0.210	10.8
600	0.321	11.3
700	0.437	11.8
800	0.558	12.3
900	0.683	12.8
1000	0.813	13.2
1100	0.946	13.5
1200	1.083	13.8
1300	1.223	14.1
1400	1.365	14.4
1500	1.510	14.6
1600	1.657	14.8

REMARKS

The recommended values are based on the data for pure samples (curves 3, 6 and 11 to 14) and are considered accurate to within ± 5%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.025 + 7.480 \times 10^{-4}\, T + 3.765 \times 10^{-7}\, T^2 - 6.191 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±7%.

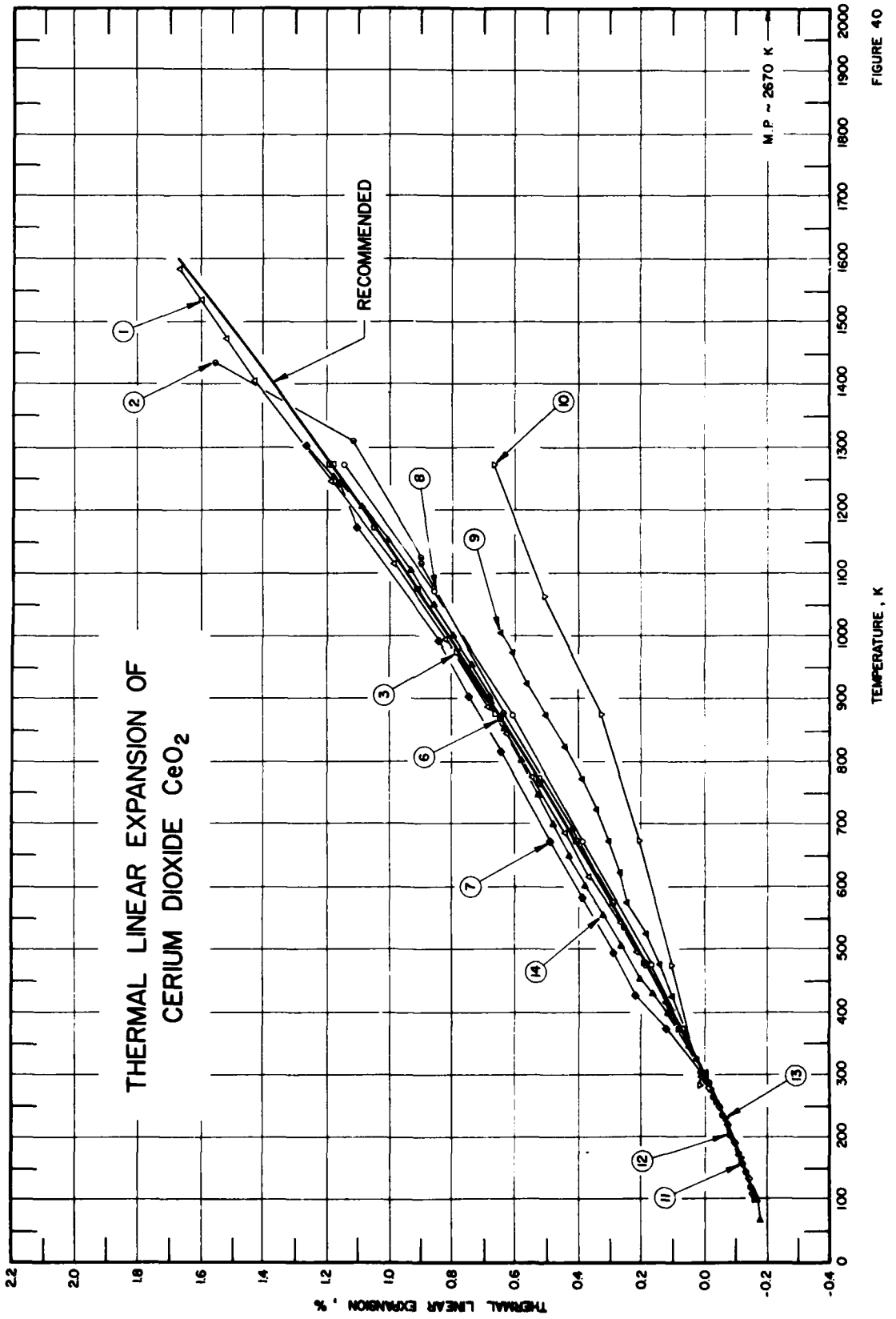

THERMAL LINEAR EXPANSION OF
CERIUM DIOXIDE CeO_2
RECOMMENDED
M.P. ~ 2670 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
6
7
8
9
10
11
12
13
14

FIGURE 40

SPECIFICATION TABLE 40. THERMAL LINEAR EXPANSION OF CERIUM DIOXIDE CeO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	68	Stecura, S. and Campbell, W.J.	1961	X	273-1583		99.9 pure specimen, supplied by Lindsay Chemical Co.; sintered at 1350 C for 24 hr, packed into alumina holder; sintered at 1450 C for 12 hr, cooled to 300 C, stored in vacuum; unit cell parameter at 273 K is 5.4085 Å.
2	63	Pears, C.D.	1963	L	294-2366	Run E-14	Specimen 2.934 in. long; obtained from Zirconium Corp. of America; pressed, sintered, melted on post inspection; expansion measured in helium atmosphere; reported error 5%.
3	14	Wilfong, R.L., Domingues, L.P., Furlong, L.R., and Finlayson, J.A.	1963	I	298-1273	Specimen I	0.1-1.0 Th, 0.001-0.01 Al, Ca, Cu, Dy, Er, Gd, Lu, Pr, Si, Tm, U, 0.0003-0.003 Fe, Mg; cubic specimen precalcined at 1200 C, 1 hr, mixed with binder (2% varsal plus 2% paraffin dissolved in benzene), hot pressed at 2600 psi to 1673 K, ground into shape, matured at 1400 C overnight, heated to 1773 K for 1 hr, and desiccated; bulk density 6.4 g cm^{-3} after expansion test measured by mercury displacement at low pressure; heating rate 5 C per min; zero-point correction of 0.0060% determined by graphical extrapolation.
4*	14	Wilfong, R.L., et al.	1963	I	298-1273	Specimen I	The above specimen; expansion measured with increasing temperature on second run; zero-point correction of 0.0060% determined by graphical extrapolation.
5*	14	Wilfong, R.L., et al.	1963	I	298-1272	Specimen II	0.03-0.3 Dy, 0.01-0.1 Na, Th, 0.003-0.03 Mg, Si, 0.001-0.01 Lu, Y, 0.0001-0.001 Yb; specimen powder mixed with 4% binder (approximately 10% polyvinyl alcohol solution), dry pressed at 19 000 psi, heated to 498 K for 2 hr to burn off binder, heated to 1273 K for 16 hr, heated to 1723 K for 1 hr, ground into shape, matured at 1723 K 1 hr and desiccated; cubic bulk density 5.1 g cm^{-3} after expansion test measured by mercury displacement at low pressure; heating rate 5 C per min; zero-point correction of 0.0060% determined by graphical extrapolation.
6	14	Wilfong, R.L., et al.	1963	I	298-1274	Specimen II	The above specimen; expansion measured with increasing temperature on second test; zero-point correction of 0.0060% determined by graphical extrapolation.
7	320	Mahanta, P.C., Hatibarua, J., and Das, R.K.	1962	X	304-1301		Spectroscopically pure; specimen supplied by Johnson, Matthey and Co., London; lattice parameter at 304 K is 5.411 Å, at 293 K 5.410 Å determined by graphical extrapolation.
8	90	Leipold, M.H. and Nielsen, T.	1964	L	298-1273		99.9 pure; specimen prepared from Research Chemical Corp, with particle size of 5 μ, reduced to particle size of less than 1 μ in fluid energy mill; hot pressed at 10 000 psi and 1423 K for 45 min, and welded two samples together by hot pressing as before.
9	91	Hummel, F.A. and Henry, E.C.	1946		302-1006		No details given; zero-point correction of 0.008% determined by graphical extrapolation.
10	93	Strekalovskii, V.N., Bessonov, A.F., Ustyantsev, V.M., and Burov, G.V.	1967	X	282-1273		Elementary cell; expansion measured in air atmosphere; lattice parameter reported at 282 K is 5.399 Å; 5.398 Å at 293 K determined by graphical extrapolation.
11	342	Gupta, M.L.	1968	X	110-300		99.9 pure powder form specimen; provided by Research Chemicals, Inc., Burbank, Calif; annealed at 1373 K for 72 hr; lattice parameter reported at 110 K is 5.4017 Å; 5.4099 Å at 293 K determined by graphical interpolation.
12	342	Gupta, M.L.	1968	X	290-121		The above specimen; expansion measured with decreasing temperature.
13	589	Gupta, M.L. and Singh, S.	1970	X	100-290		Similar to the above specimen.
14	594	Hatibarua, J. and Mahanta, P.C.	1972	X	69-1300		99.99 pure, 0.0008 Mn, 0.0007 Fe, 0.0001 Mg, 0.01 $Y + O_2$; sample from Johnson and Matthey's; specimen heated and maintained at 1300 K for 24 hr, then cooled to room temperature.

* Not shown in figure.

DATA TABLE 40. THERMAL LINEAR EXPANSION OF CERIUM DIOXIDE CeO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
273	-0.020
299	0.008
391	0.106
413	0.128
493	0.220
541	0.278
619	0.368
688	0.442
776	0.553
843	0.629
889	0.692
993	0.825
1118	0.997
1248	1.184
1404	1.417
1473	1.521
1534	1.603
1583	1.677
CURVE 2	
294	0.00
395	0.12*
539	0.26
693	0.42
879	0.64
1116	0.91
1124	0.91
1310	1.12
1438	1.56
1683	2.64*
1855	3.19*
2105	4.04*
2110	4.12*
2177	4.14*
2227	3.40*
2310	2.70*
2366	2.14*
2366	1.46*
CURVE 3	
298	0.0060*
372	0.0781
472	0.1847
573	0.2981
CURVE 3 (cont.)	
673	0.4139
773	0.5338
877	0.6617
973	0.7856
1077	0.9219
1175	1.0507
1273	1.1835
CURVE 4*	
298	0.0060
370	0.0778
472	0.1869
573	0.2985
672	0.4142
771	0.5326
874	0.6601
973	0.7860
1076	0.9211
1174	1.0523
1273	1.1807
CURVE 5*	
298	0.0060
373	0.0800
471	0.1849
573	0.2988
674	0.4165
776	0.5385
873	0.6589
974	0.7886
1077	0.9239
1176	1.0573
1272	1.1865
CURVE 6	
298	0.0060*
377	0.0838
477	0.1905
573	0.2982
672	0.4129
769	0.5295
870	0.6554
973	0.7867*
CURVE 6 (cont.)	
1072	0.9178*
1172	1.0516*
1274	1.1903
CURVE 7	
304	0.0184
373	0.1293
427	0.2218
494	0.2957
582	0.3881
674	0.4990
818	0.6469
902	0.7578
992	0.8502
1176	1.109
1249	1.164
1301	1.275
CURVE 8	
298	0.005*
473	0.178
673	0.386
873	0.607
1073	0.861
1273	1.154
CURVE 9	
302	0.008
324	0.028
373	0.067*
423	0.107
473	0.147
523	0.187
573	0.227
623	0.268
674	0.309
722	0.347
772	0.388
823	0.451
872	0.509
924	0.562
973	0.613
1006	0.646
CURVE 10	
282	0.0185
473	0.111
673	0.204
873	0.333
1069	0.519
1273	0.667
CURVE 11	
110	-0.1516
132	-0.1405
160	-0.1183
190	-0.0980
220	-0.0702
250	-0.0425
280	-0.0111
300	0.0111*
CURVE 12	
290	0.0111
265	-0.0240
235	-0.0536
205	-0.0795
175	-0.1091
145	-0.1312
121	-0.1442
CURVE 13	
100	-0.1571
110	-0.1516*
130	-0.1405*
150	-0.1275*
170	-0.1128
190	-0.0961*
210	-0.0795*
230	-0.0610
260	-0.0314
290	0.000*
CURVE 14‡	
69	-0.175
95	-0.164
148	-0.129*
CURVE 14 (cont.)‡	
201	-0.085*
245	-0.046*
293	0.000*
300	0.007*
347	0.058
376	0.097*
397	0.130
427	0.177
453	0.214
502	0.276
552	0.334
600	0.386
650	0.437
699	0.485
749	0.533
801	0.583
853	0.635
903	0.688
951	0.741
1001	0.801
1051	0.866
1104	0.940
1153	1.013
1202	1.091
1254	1.181
1300	1.267

*Not shown in figure.
‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$

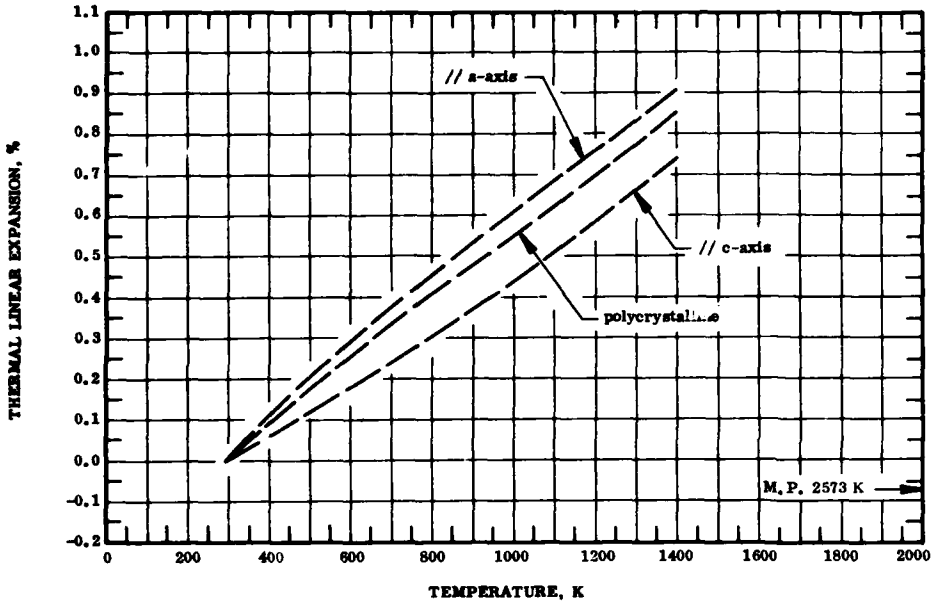
DATA TABLE 40. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CERIUM DIOXIDE CeO_2

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 14*,‡	
69	4.2
95	4.7
148	8.2
201	8.7
245	9.0
293	10.0
300	10.0
347	11.9
376	14.6
397	16.8
427	14.9
453	13.2
502	12.1
552	11.2
600	10.5
650	9.8
699	9.6
749	9.6
801	9.8
853	10.2
903	10.9
951	11.5
1001	12.4
1051	13.5
1104	14.4
1153	15.4
1202	16.6
1254	18.0
1300	19.1

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 41R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF CHROMIUM OXIDE Cr_2O_3



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	8.8
350	0.029	0.060	0.050	8.6
400	0.056	0.110	0.092	8.4
500	0.113	0.205	0.174	8.1
600	0.173	0.294	0.253	7.8
700	0.236	0.377	0.330	7.6
800	0.301	0.457	0.405	7.4
900	0.370	0.533	0.478	7.3
1000	0.440	0.607	0.552	7.3
1100	0.513	0.681	0.625	7.4
1200	0.587	0.755	0.700	7.5
1300	0.663	0.831	0.775	7.6
1400	0.740	0.910	0.852	7.8

REMARKS

The provisional values for the axial thermal expansion are based on the data for pure samples (curves 3 and 8 for // c-axis, curves 2 and 9 for // a-axis). These values are considered accurate to within ±10% and are represented approximately by the following equation:

// c-axis: $\Delta L/L_0 = -0.130 + 3.785 \times 10^{-4}\ T + 2.379 \times 10^{-7}\ T^2 - 4.591 \times 10^{-11}\ T^3$

// a-axis: $\Delta L/L_0 = -0.356 + 1.376 \times 10^{-3}\ T - 6.001 \times 10^{-7}\ T^2 + 1.876 \times 10^{-10}\ T^3$

polycrystalline: $\Delta L/L_0 = -0.280 + 1.038 \times 10^{-3}\ T - 3.122 \times 10^{-7}\ T^2 + 1.062 \times 10^{-10}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

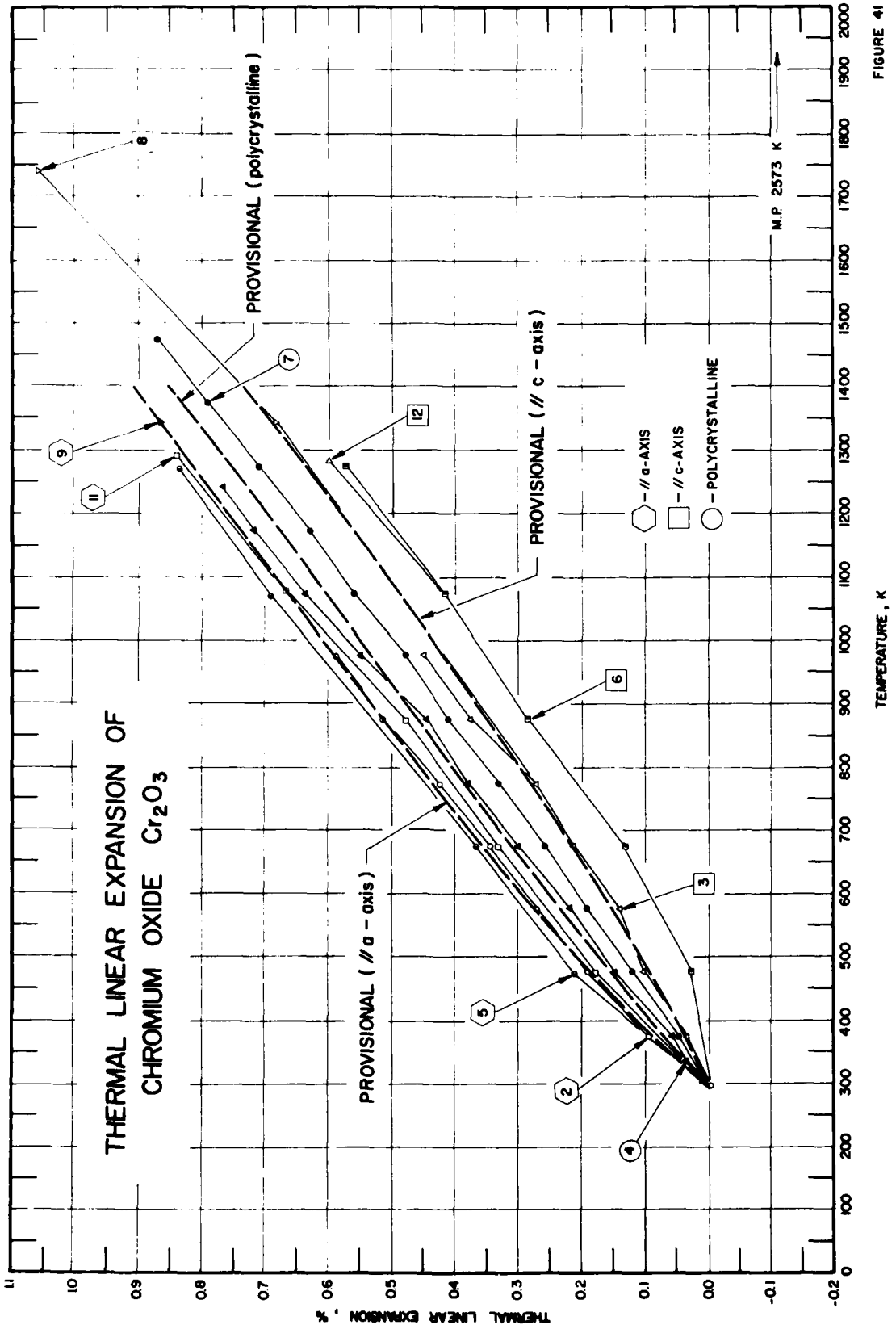

THERMAL LINEAR EXPANSION OF
CHROMIUM OXIDE Cr_2O_3
PROVISIONAL (polycrystalline)
PROVISIONAL (// c - axis)
PROVISIONAL (// a - axis)
M.P 2573 K
- // a-AXIS
- // c-AXIS
- POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K

FIGURE 41

SPECIFICATION TABLE 41. THERMAL LINEAR EXPANSION OF CHROMIUM OXIDE Cr_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	69	Finlay, G. R.	1952		293, 1073		No details given.
2	94	Brooksbank, D. and Andrews, K. W.	1968	X	296-975		Specpure specimen; obtained from Johnson-Matthey Co.; powder, coated onto hot junction of thermocouple, camera furnace at pressure of $\sim 10^{-3}$ torr; $CrK\alpha$ radiation with exposure 4-6 hr; expansion measured along a-axis; lattice parameter reported at 296 K is 4.9564 Å; 4.9570 Å at 293 K determined by graphical extrapolation.
3	94	Brooksbank, D. and Andrews, K. W.	1968	X	295-977		The above specimen; expansion measured along c-axis; lattice parameter reported at 295 K is 13.5860 Å; 13.5858 Å at 293 K determined by graphical extrapolation.
4	95	Williams, R. M.	1967	L	339-1246		J. T. Baker pure grade; bar specimen 0.95 x 1.27 x 5.93 cm; pressed at pressures of 5000, 10 000, and 15 000 psi; fired at 1873 K for 2 hr after slow heating; zero-point correction of -0.01% determined by graphical extrapolation.
5	29	Merz, K. M. and Kirchner, H. P.	1960	X	299-1273		Reagent grade specimen; expansion measured along a-axis; lattice constant reported at 299.2 K is 4.9584 Å; zero-point correction of 0.048% determined by graphical extrapolation.
6	29	Merz, K. M. and Kirchner, H. P.	1960	X	299-1273		The above specimen; expansion measured along c-axis; lattice constant reported at 299.2 K is 13.5960 Å; zero-point correction of ±0.000% determined by graphical extrapolation.
7	97	Rigby, G. R., Levell, G. H. G., and Green, A. T.	1946	L	373-1473		Specimen prepared by reducing CrO_3; bonding with gum arabic; firing to 1803 K; specific gravity 5.2; zero-point correction of 0.05% determined by graphical extrapolation.
8	593	Kukielka, H.	1972	X	298-1943		Expansion measured along c-axis; 13.589 Å reported at 298 K; 13.587 Å at 293 K used for data conversion.
9	593	Kukielka, H.	1972	X	298-1943		The above specimen; expansion measured along a-axis; 4.9590 Å reported at 298 K; 4.957 Å at 293 K used for data conversion.
10*	599	Samsonov, G. V., Grebenkina, V. G., and Klimenko, V. S.	1971	L	293, 1373		Reported error is 1.5%.
11	647	Merz, K. M., Brown, W. R., and Kirchner, H. P.	1962	X	303-1291		Powder specimen prepared by crushing disks in alumina mortar to pass 0.044 mm standard sieve; thermal expansion measured along a-axis; zero-point correction 0.01%.
12	647	Merz, K. M., et al.	1962	X	293-1283		The above specimen; thermal expansion measured along c-axis.

*Not shown in figure.

DATA TABLE 41. THERMAL LINEAR EXPANSION OF CHROMIUM OXIDE Cr_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
293	0.000
1073	0.936

CURVE 2

T	$\Delta L/L_0$
296	-0.0121*
375	0.0989
475	0.1937
573	0.2744
674	0.3490
774	0.4297
877	0.5144
975	0.5891

CURVE 3

T	$\Delta L/L_0$
295	-0.0052*
375	0.0390
475	0.1038
575	0.1413
674	0.2157
776	0.2753
876	0.3768
977	0.4519

CURVE 4

T	$\Delta L/L_0$
339	0.04
373	0.06
473	0.15
573	0.22
673	0.30
773	0.38
873	0.45
973	0.55
1073	0.64
1173	0.72
1246	0.77

CURVE 5

T	$\Delta L/L_0$
299	0.048*
473	0.217
673	0.369
873	0.514*
1073	0.693
1273	0.839

CURVE 6

T	$\Delta L/L_0$
299	0.000*
473	0.029
673	0.132
873	0.282
1073	0.413
1273	0.571

CURVE 7

T	$\Delta L/L_0$
373	0.05
473	0.12
573	0.19
673	0.26
773	0.33
873	0.41
973	0.48
1073	0.56
1173	0.63
1273	0.71
1373	0.79
1473	0.87

CURVE 8

T	$\Delta L/L_0$
298	0.015*
1343	0.684
1743	1.060
1943	1.310*

CURVE 9

T	$\Delta L/L_0$
298	0.040*
1343	0.865
1743	1.253*
1943	1.521*

CURVE 10*

T	$\Delta L/L_0$
293	0.000
1373	0.013

CURVE 11

T	$\Delta L/L_0$
303	0.01
473	0.18
673	0.33
873	0.48

CURVE 11 (cont.)

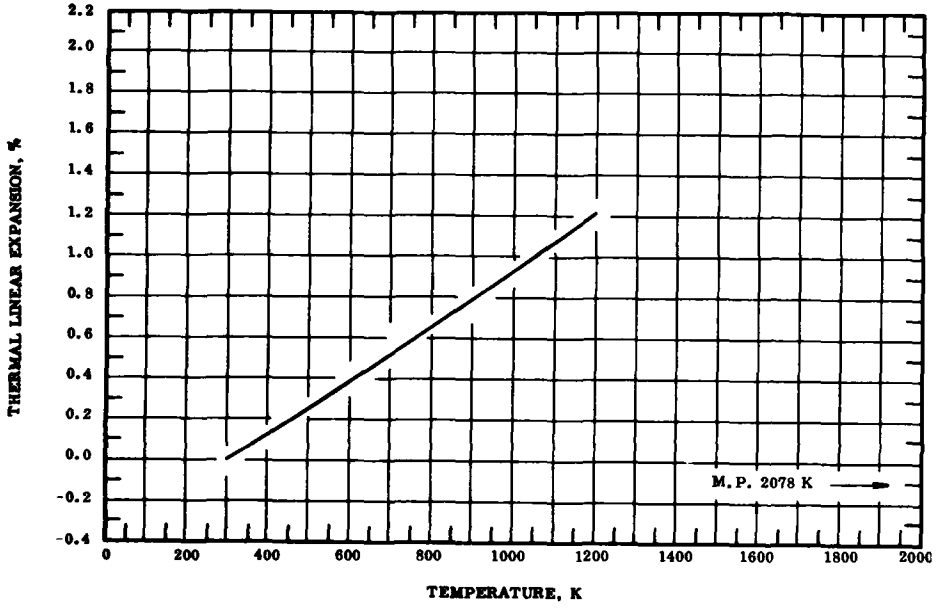
T	$\Delta L/L_0$
1080	0.67
1291	0.84

CURVE 12

T	$\Delta L/L_0$
293	0.00*
473	0.32*
673	0.13*
873	0.28*
1074	0.42*
1283	0.60

* Not shown in figure.

FIGURE AND TABLE NO. 42R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF COBALT OXIDE CoO



RECOMMENDED VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

T	$\Delta L/L_0$	α
293	0.000	12.2
400	0.132	12.5
500	0.258	12.8
600	0.388	13.1
700	0.520	13.4
800	0.655	13.6
900	0.793	13.9
1000	0.933	14.1
1100	1.076	14.4
1200	1.221	14.6

REMARKS

The recommended values are based on the data reported in curves 1 to 3 and are considered accurate to within ±5%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.343 + 1.121 \times 10^{-3}\, T + 1.697 \times 10^{-7}\, T^2 - 1.538 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±7%.

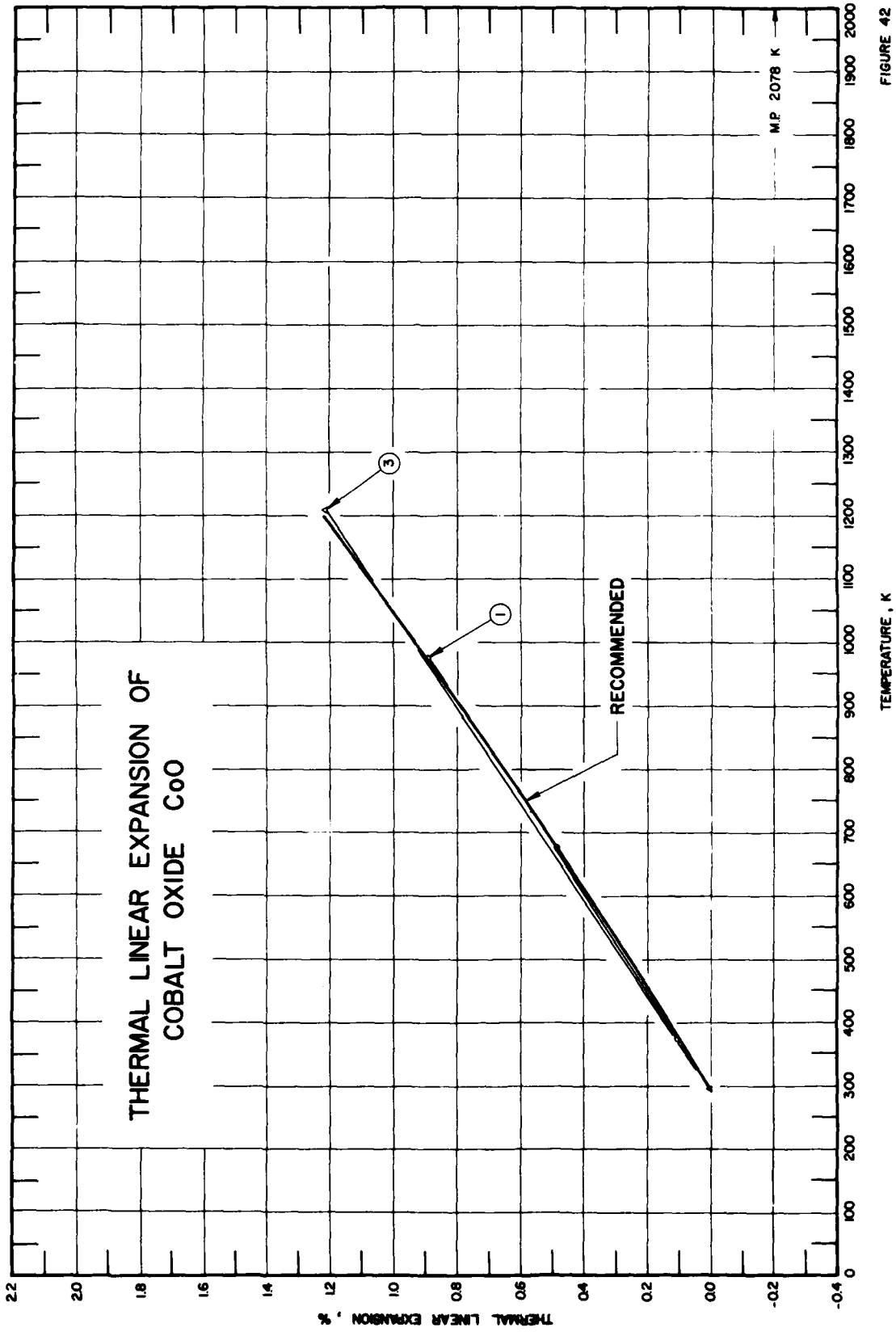

THERMAL LINEAR EXPANSION OF
COBALT OXIDE CoO
M.P. 2078 K
RECOMMENDED
1
3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 42

SPECIFICATION TABLE 42. THERMAL LINEAR EXPANSION OF COBALT OXIDE CoO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	128	Wisely, H.R.	1962	L	373-973		Bar specimen; 0.25 x 0.375 x 2 in.; formed under pressure 26,000 psi; sintered in air atm 16 hrs; reported error ±1.5%.
2*	591	Rechtin, M.D. and Averbach, B.L.	1971	L	277-302		Chemical analysis: Co^{2+} to O^{2-} ratio of 1.001 to 1.000 with 0.15% Ni^{2+} impurity; measurements along (001) direction of CoO single crystal, dilatometer sensitivity, 10^{-6} cm; crystal cleaved along (001) planes from a large boule grown by flame fusion and annealed; temperature controlled to ±0.1 K and 30 min. temperature stabilization at each point.
3	592	Angerman, C.L. and Ross, C.P.	1969	X	293,1208		A cold pressing and sintering technique used to make wafers of sample.

DATA TABLE 42. THERMAL LINEAR EXPANSION OF COBALT OXIDE CoO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
373	0.102
673	0.486
973	0.894
CURVE 2*	
278	-0.200
279	-0.189
280	-0.173
282	-0.156
283	-0.140
284	-0.124
285	-0.113
286	-0.095
287	-0.070
288	-0.055
289	-0.014
290	-0.008
292	-0.002
293	0.000
294	0.002

T	$\Delta L/L_0$
CURVE 2 (cont.)*	
295	0.004
297	0.007
299	0.009
300	0.011
302	0.014
CURVE 3	
293	0.00
1208	1.22

*Not shown in figure.

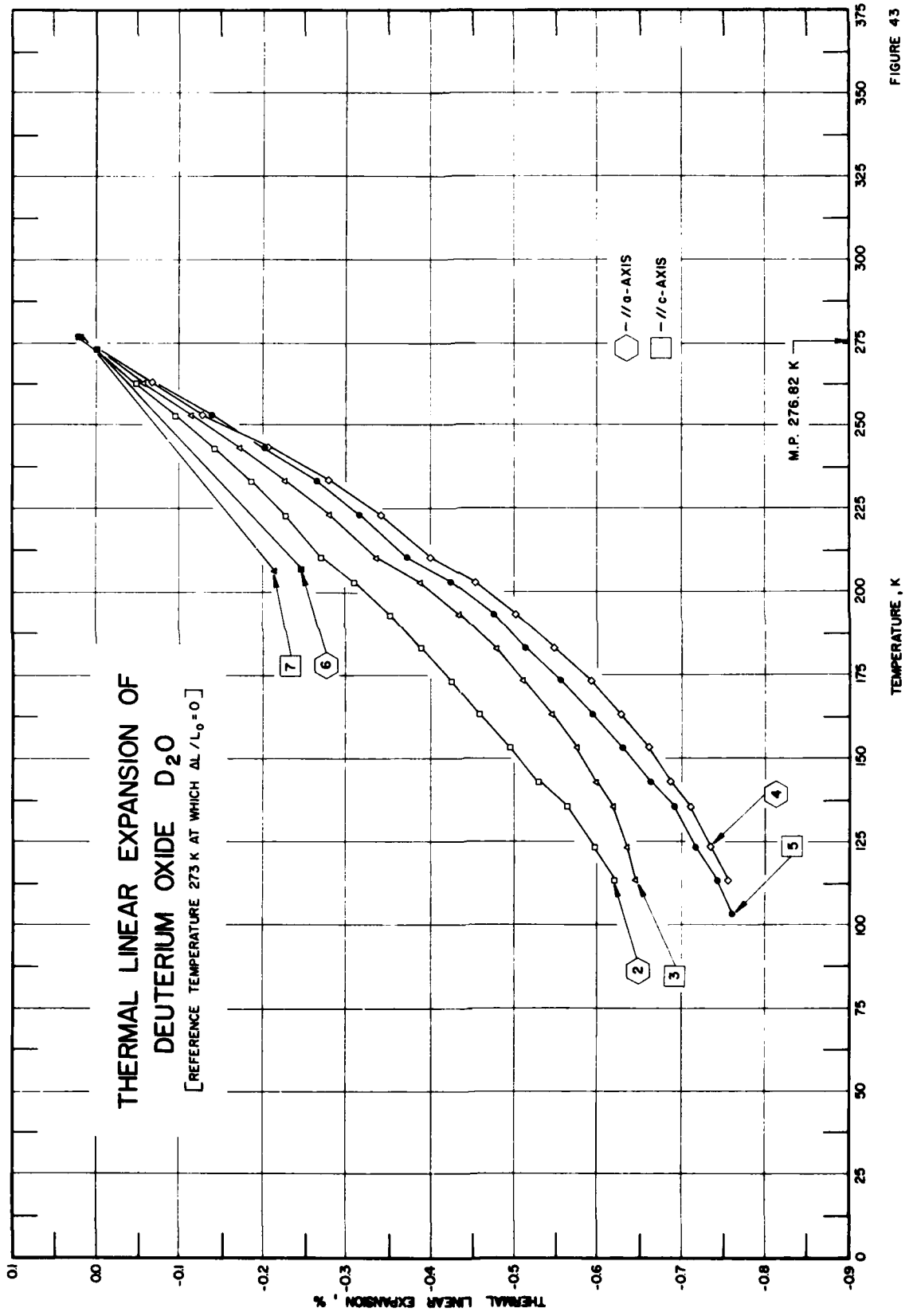

THERMAL LINEAR EXPANSION OF
DEUTERIUM OXIDE D_2O
[REFERENCE TEMPERATURE 273 K AT WHICH $\Delta L / L_0 = 0$]
M.P. 276.82 K
// a-AXIS
// c-AXIS
2
3
4
5
6
7
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375

FIGURE 43

SPECIFICATION TABLE 43. THERMAL LINEAR EXPANSION OF DEUTERIUM OXIDE D_2O

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	110	Dantl, G.	1962	I	18-270		100.0 pure; single crystal specimen; this curve is here reported using 273 K as reference temperature at which $\Delta L/L_0 = 0$; coefficient of thermal linear expansion also reported.
2	111	Handler, E. S.	1968	X	113-263		99.5 pure specimen; obtained from General Dynamics, San Carlos, Calif.; lattice constant expansion measured along a-axis; 4.5222 Å reported at 263.2 K; 4.5244 Å at 273.2 K determined by graphical extrapolation; this curve is here reported using 273.2 K as reference temperature at which $\Delta L/L_0 = 0$.
3	111	Handler, E. S.	1968	X	113-263		The above specimen; lattice expansion measured along c-axis; 7.3664 Å reported at 263.2 K; 7.3706 Å at 273.2 K determined by graphical extrapolation; this curve is here reported using 273.2 K as reference temperature at which $\Delta L/L_0 = 0$.
4	111	Handler, E. S.	1968	X	113-263	D_2O^{18}	99.0 D, 91. O^{18}, 1.1 O^{17}; specimen obtained from Dr. D. Samuels of Weitzman Inst. (Rehovat, Israel); lattice expansion measured along a-axis; 4.5258 Å reported at 263.2 K; 4.5288 Å at 273.2 K determined by graphical extrapolation; this curve is here reported using 273.2 K as reference temperature at which $\Delta L/L_0 = 0$.
5	111	Handler, E. S.	1968	X	103-263	D_2O^{18}	The above specimen; lattice expansion measured along c-axis; 7.3668 Å reported at 263.2 K; 7.3717 Å at 273.2 K determined by graphical extrapolation; this curve is here reported using 273.2 K as reference temperature at which $\Delta L/L_0 = 0$.
6	363	Megaw, H. D.	1934	X	207-277		Single crystal specimen; grown by inserting Lindemann glass tube into holder in contact with cooling mixture of acetone and solid carbon dioxide; plane (5050) used with $CuK\alpha$ radiation for measurement of a-axis of unit cell; 4.5165 Å reported at 273.2 K; this curve is here reported using 273.2 K as reference temperature at which $\Delta L/L_0 = 0$.
7	363	Megaw, H. D.	1934	X	207-277		Similar to the above specimen; plane (0008) used with $CoK\alpha$ radiation for measurement of c-axis of unit cell; 7.3537 Å reported at 273.2 K; this curve is here reported using 273.2 K as reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

DATA TABLE 43. THERMAL LINEAR EXPANSION OF DEUTERIUM OXIDE D_2O

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡,‡		CURVE 1 (cont.)*,‡,‡		CURVE 2 (cont.)‡		CURVE 3 (cont.)‡		CURVE 4 (cont.)‡		CURVE 5 (cont.)‡	
18	-0.575	220	-0.228	223	-0.2276	223	-0.2795	223	-0.3400	213	-0.3717
30	-0.581	240	-0.148	233	-0.1856	233	-0.2252	233	-0.2760	223	-0.3188
40	-0.586	250	-0.106	243	-0.1414	243	-0.1709	243	-0.2076	233	-0.2632
50	-0.591	260	-0.061	253	-0.0950	253	-0.1140	253	-0.1369	243	-0.2021
60	-0.594	270	-0.015	263	-0.0486	263	-0.0570	263	-0.0662	253	-0.1397
70	-0.593									263	-0.0665*
80	-0.587	CURVE 2‡		CURVE 3‡		CURVE 4‡		CURVE 5‡		CURVE 6‡	
90	-0.578										
100	-0.564	113	-0.6210	113	-0.6472	113	-0.7552	103	-0.7597	207	-0.2435
110	-0.548	123	-0.5967	123	-0.6363	123	-0.7331	113	-0.7420	273	0.0000
120	-0.530	133	-0.5658	133	-0.6200	133	-0.7110	123	-0.7189	277	0.0221
130	-0.509	143	-0.5304	143	-0.5997	143	-0.6867	133	-0.6918		
140	-0.486	153	-0.4950	153	-0.5752	153	-0.6602	143	-0.6633	CURVE 7‡	
150	-0.461	163	-0.4597	163	-0.5468	163	-0.6293	153	-0.6308		
160	-0.434	173	-0.4265	173	-0.5128	173	-0.5918	163	-0.5955		
170	-0.405	183	-0.3890	183	-0.4776	183	-0.5498	173	-0.5562	207	-0.2134
180	-0.373	193	-0.3514	193	-0.4355	193	-0.5012	183	-0.5155	273	0.0000*
190	-0.340	203	-0.3116	203	-0.3894	203	-0.4527	193	-0.4721	277	0.0203
200	-0.304	213	-0.2696	213	-0.3365	213	-0.3997	203	-0.4232		

DATA TABLE 43. COEFFICIENT OF THERMAL LINEAR EXPANSION OF DEUTERIUM OXIDE D_2O

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

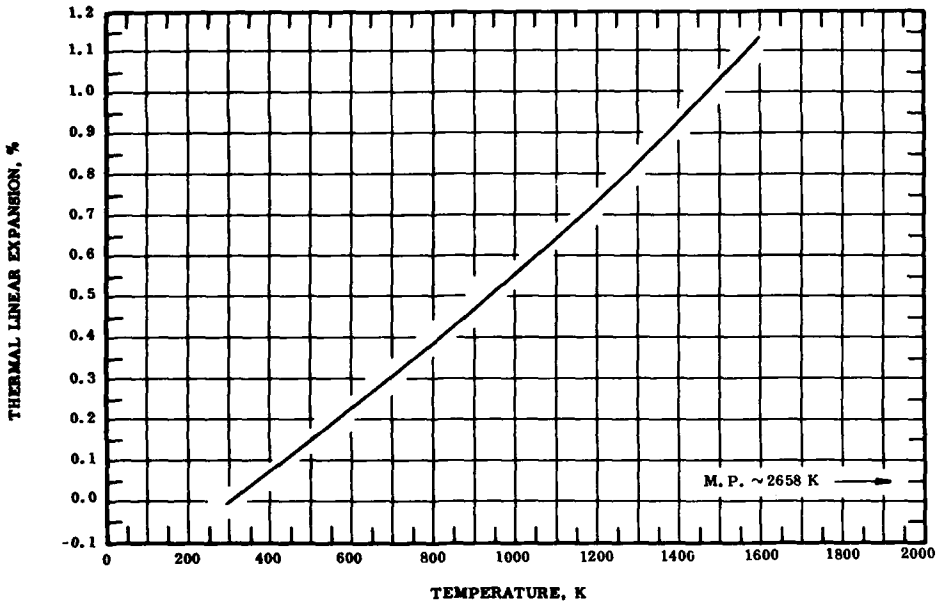
T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡	
18	-4.4	170	30.3
30	-5.6	180	32.7
40	-5.7	190	34.9
50	-4.3	200	36.8
60	-1.3	220	39.0
70	3.5	240	41.1
80	7.9	250	43.3
90	11.8	260	45.5
100	14.9	270	47.8
110	17.3		
120	19.6		
130	21.6		
140	24.0		
150	26.1		
160	28.2		

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

‡ This curve is here reported using 273 K as reference temperature at which $\Delta L/L_0 = 0$.

FIGURE AND TABLE NO. 44R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF DYSPROSIUM OXIDE Dy_2O_3



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	7.5
400	0.081	7.6
500	0.157	7.6
600	0.234	7.8
700	0.312	7.9
800	0.392	8.1
900	0.474	8.3
1000	0.559	8.6
1100	0.646	8.9
1200	0.734	9.2
1300	0.831	9.6
1400	0.929	10.0
1500	1.032	10.5
1600	1.139	10.9

REMARKS

The recommended values are based on the data for pure samples and are considered accurate to within ±3%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.221 + 7.617 \times 10^{-4} T - 4.267 \times 10^{-6} T^2 + 6.106 \times 10^{-11} T^3$$

The tabulated values for the coefficeint of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±5%.

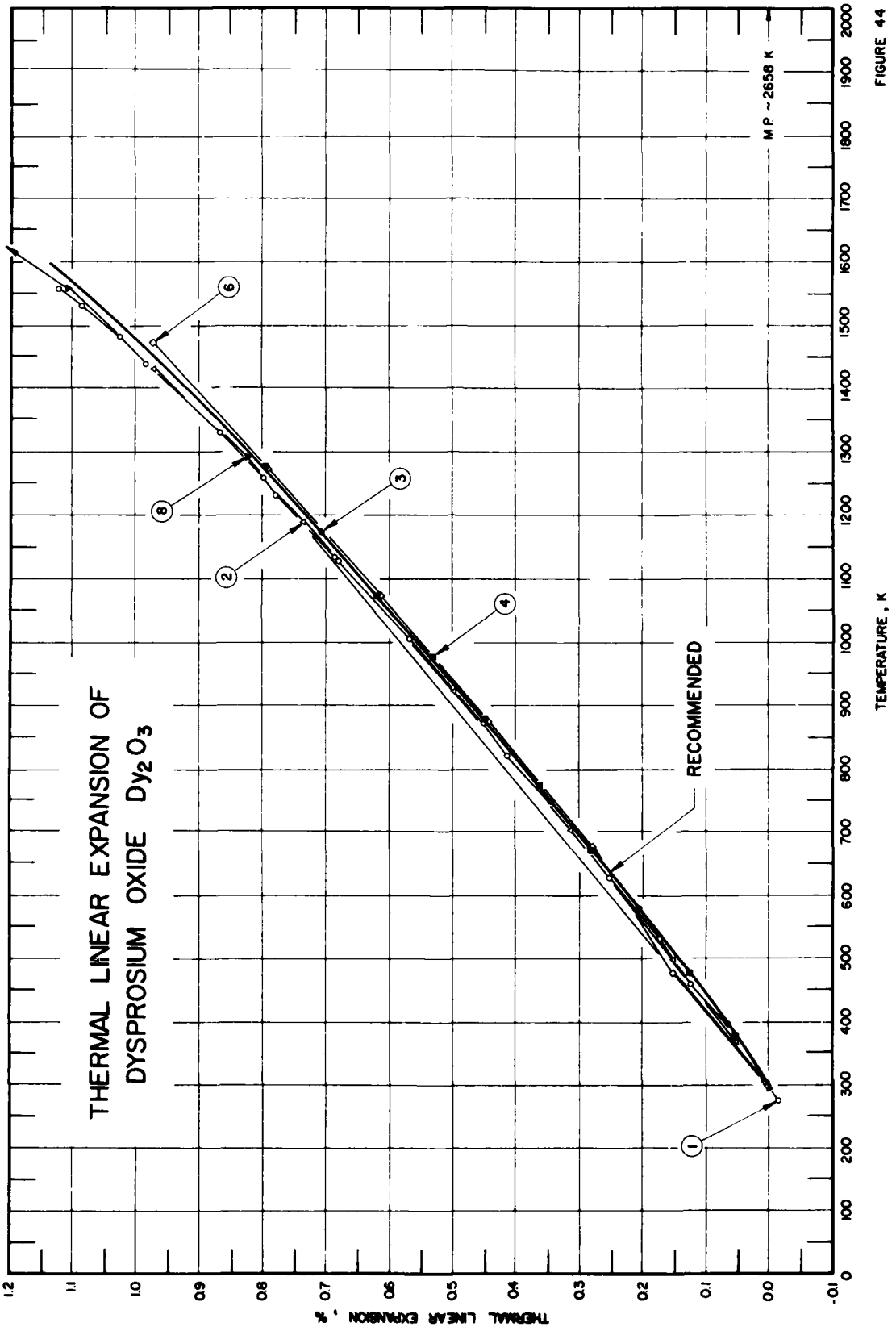

THERMAL LINEAR EXPANSION OF
DYSPROSIUM OXIDE Dy_2O_3
RECOMMENDED
M P ~2658 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
4
6
8

FIGURE 44

SPECIFICATION TABLE 44. THERMAL LINEAR EXPANSION OF DYSPROSIUM OXIDE Dy_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	68	Stecura, S. and Campbell, W.J.	1961	X	273-1558		99 pure, major impurities 0.01-0.1 Ca, 0.001-0.01 Mg; cubic specimen supplied by Michigan Chemical Corp; sintered at 1423 K for 24 hr; packed into alumina holder, sintered at 1423 K, cooled to 623 K and stored in vacuum desiccator; unit cell parameter reported at 273 K is 10.6530 Å; reported error ±2%; zero-point correction of -0.013% determined by graphical interpolation.
2	68	Stecura, S. and Campbell, W.J.	1961	X	1427-366		The above specimen; expansion measured with decreasing temperature; zero-point correction -0.013% determined by the above graphical interpolation.
3	14	Wilfong, R.L., Domingues, L.P., Furlong, L.R., and Finlayson, J.A.	1963	I	298-1174		0.3-3.0 Y, 0.01-0.1 Si, 0.003-0.03 Ca, 0.0003-0.003 Mg; cubic specimen; powder calcined at 1473 K for 1 hr, mixed with binder (2% varsal plus 2% paraffin dissolved in benzene), dry pressed at 25 000 psi, sintered at 1773 K for 1 hr, ground into shape, heated to 1773 K for 1 hr, reground, heated to 1673 K for 3 hr, and desiccated; bulk density 7.2 g cm^{-3}; heating rate 5 C per min; zero-point correction of 0.0040% determined by graphical extrapolation.
4	14	Wilfong, R.L., et al.	1963	I	298-1275		The above specimen; expansion measured on second test; zero-point correction of 0.0040% determined by graphical extrapolation.
5*	14	Wilfong, R.L., et al.	1963	I	298-1271		The above specimen; expansion measured on third test; zero-point correction of 0.0040% determined by graphical extrapolation.
6	99	Brown, W.R. and Kirchner, H.P.	1961	X	298-1473		99+ pure; specimen supplied by Research Chemicals, Inc., Burbank, Calif.; expansion measured with $CrK\alpha$ radiation; lattice parameter reported at 298 K is 10.6677 Å; 10.6673 Å at 293 K determined by graphical extrapolation.
7*	87	Ploetz, G.L., Krystyniak, C.W., and Dumas, H.E.	1957	I	322-1118		Conical specimen; about 4.7 mm high; cut from pellet which hot-pressed in graphite mold into 0.165 in. O.D., 0.75 in. long; 95% theoretical density; expansion values reported by assuming the length of specimen at 293 K equal to that at 303 K.
8	590	Rudenko, V.S. and Boganov, A.G.	1970	X	293-2372		Cubic modification (c form); lattice parameter reported at 293 K is 10.664 Å.

*Not shown in figure.

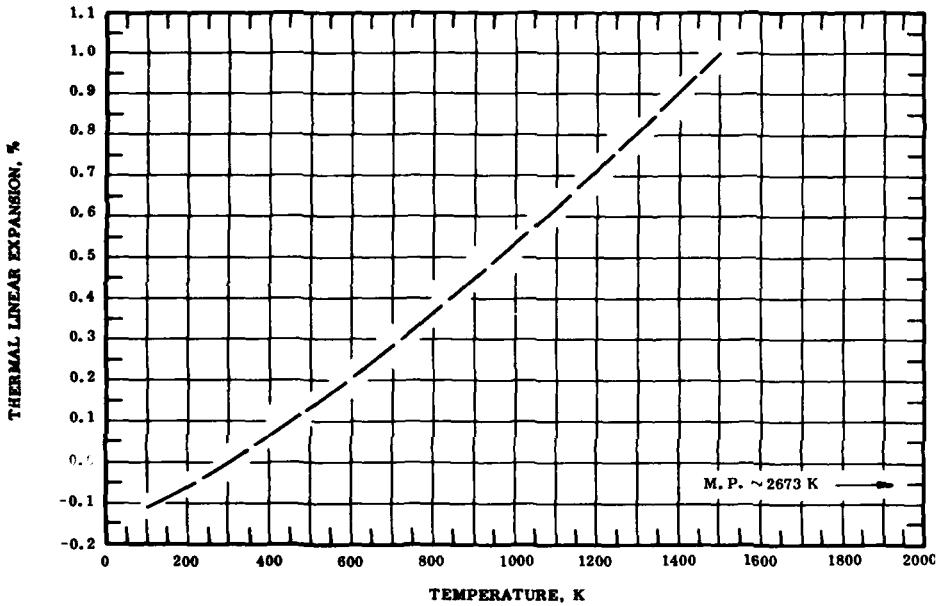
DATA TABLE 44. THERMAL LINEAR EXPANSION OF DYSPROSIUM OXIDE Dy_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
273	-0.013
300	0.005
393	0.067
458	0.126
528	0.177
625	0.256
749	0.348
819	0.416
870	0.454
1003	0.571
1125	0.681
1131	0.688
1228	0.781
1258	0.800
1327	0.871
1438	0.987
1480	1.029
1529	1.087
1558	1.123
CURVE 2	
1427	0.974
1186	0.739
920	0.500
699	0.315
492	0.153
366	0.053
CURVE 3	
298	0.0040*
577	0.2097
872	0.4501*
1174	0.7089
CURVE 4	
298	0.0040*
375	0.0558
473	0.1297
575	0.2076*
670	0.2841
772	0.3667
875	0.4516
973	0.5347
CURVE 4 (cont.)	
1073	0.6209
1173	0.7075*
1275	0.7983
CURVE 5*	
298	0.0040
371	0.0539
472	0.1289
577	0.2103
673	0.2862
775	0.3688
873	0.4501
972	0.5339
1073	0.6207
1174	0.7089
1271	0.7948
CURVE 6	
298	0.0037
473	0.1565
673	0.2822
873	0.4481
1073	0.6159
1273	0.7949
1473	0.9777
CURVE 7*	
322	0.017
373	0.046
472	0.117
575	0.205
676	0.297
778	0.385
876	0.482
976	0.566
1078	0.650
1118	0.675
CURVE 8	
293	0.000
305	0.019
1189	0.825
CURVE 8 (cont.)	
1558	1.107
1792	1.435*
2039	1.604*
2053	1.510*
2069	1.510*
2269	1.810*
2275	1.782*
2309	1.932*
2372	1.885*

*Not shown in figure.

FIGURE AND TABLE NO. 45R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ERBIUM OXIDE Er_2O_3



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
100	-0.110	5.6
200	-0.060	6.0
293	0.000	6.3
400	0.067	6.7
500	0.135	7.1
600	0.208	7.4
700	0.283	7.7
800	0.362	8.1
900	0.444	8.4
1000	0.530	8.7
1100	0.618	9.0
1200	0.709	9.3
1300	0.804	9.6
1400	0.901	9.8
1500	1.000	10.0

REMARKS

The provisional values are considered accurate to within ±7% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.172 + 5.196 \times 10^{-4} T + 1.970 \times 10^{-7} T^2 - 1.491 \times 10^{-11} T^3$$

The tabulated values for the coefficeint of thermal expansion are derived from the experimental data and the values obtained by differentiating the above equation. These values are considered accurate to about ±10%.

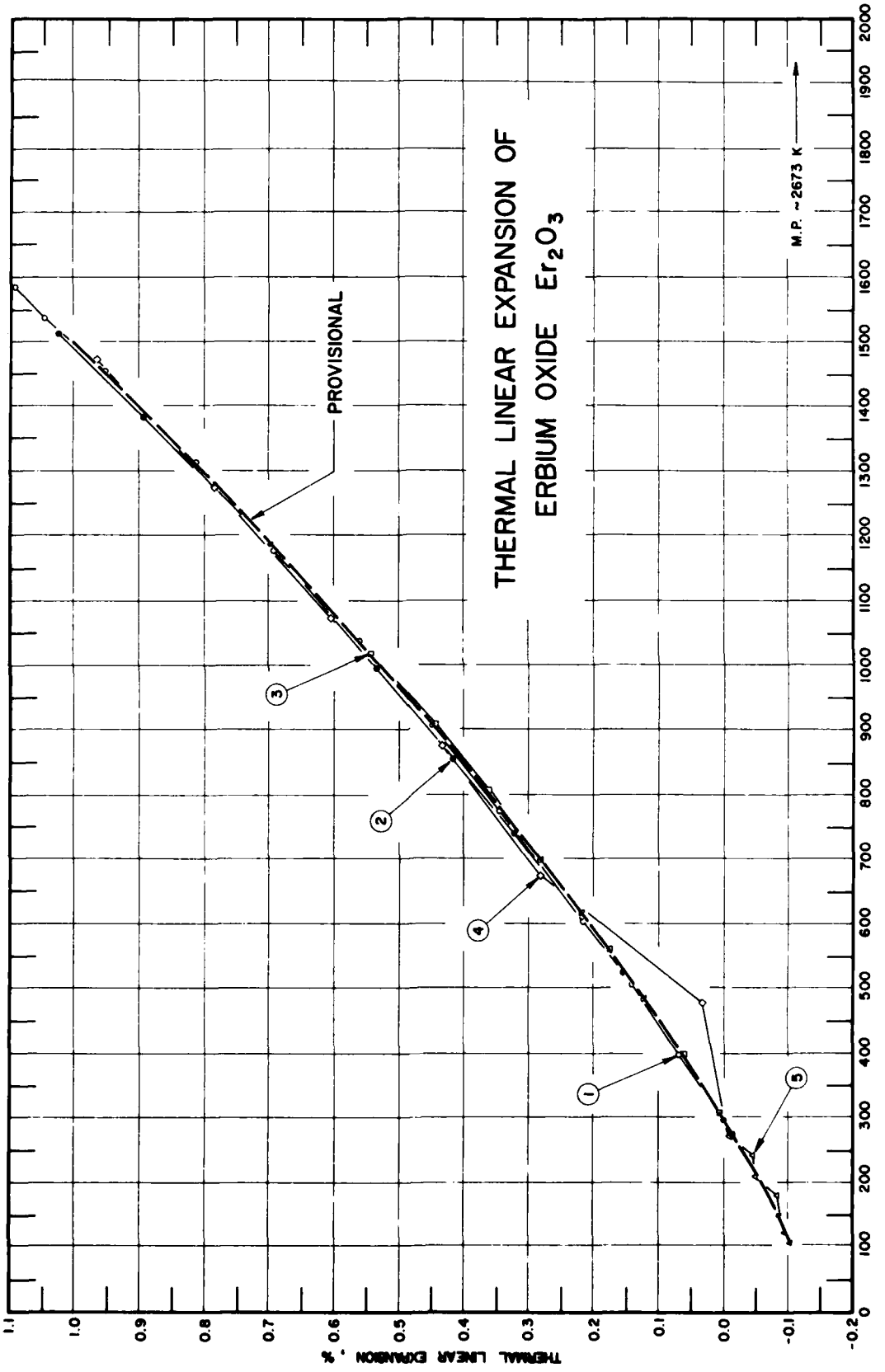

THERMAL LINEAR EXPANSION OF
ERBIUM OXIDE Er_2O_3
PROVISIONAL
M.P. ~2673 K
1
2
3
4
5
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 45

SPECIFICATION TABLE 45. THERMAL LINEAR EXPANSION OF ERBIUM OXIDE Er_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	68	Stecura, S. and Campbell, W.J.	1961	X	273-1585		99.9 pure, cubic type structure specimen; obtained from Lindsay Chemical Co., Ill.; sintered at 1573 K for 24 hr, packed in alumina holder, sintered at 1623 K for 12 hr, cooled to 573 K and stored in vacuum; lattice constant reported at 273 K is 10.5450 Å; zero-point correction of -0.012% determined by graphical interpolation.
2	68	Stecura, S. and Campbell, W.J.	1961	X	1511-521		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.012% determined by graphical extrapolation.
3	96	Singh, H.P. and Dayal, B.	1969	X	305-1015		B.C. cubic structure specimen; powder annealed at 909 K for 8 hr, filled into quartz capillary of internal diameter about 0.3 mm; lattice parameter reported at 305 K is 10.5490 Å; 10.5482 Å at 293 K determined by graphical extrapolation; coefficient of linear expansion also reported.
4	99	Brown, W.R. and Kirchner, H.P.	1961	X	298-1473		99+ pure specimen; obtained from Research Chemical Inc.; expansion measured with Cr Kα radiation; lattice constant reported at 298 K is 10.5473 Å; 10.5470 Å at 293 K determined by graphical extrapolation.
5	100	Singh, S., Davenport, J.C., and Mills, N.D.	1970	X	103-300		99.9 pure; powder specimen obtained from Research Chemical Inc.; expansion measured with Cr Kα radiation; lattice parameter reported at 103 K is 10.5364 Å; 10.5472 Å at 293 K determined by graphical interpolation.
6*	332	Mills, N.D.	1965	X	102-300		99.9+ pure; lattice parameter reported at 102 K is 10.53607 Å; 10.54675 Å at 293 K determined by graphical interpolation.

*Not shown in figure.

DATA TABLE 45. THERMAL LINEAR EXPANSION OF ERBIUM OXIDE Er_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
273	-0.012
296	0.002
398	0.071
502	0.143
601	0.218
775	0.348
906	0.451
1038	0.561
1179	0.694
1311	0.815
1454	0.957
1537	1.049
1585	1.091
CURVE 2	
1511	1.024
1383	0.893
1186	0.698
993	0.534
855	0.418
740	0.322
521	0.158
CURVE 3	
305	0.0075
398	0.0682
480	0.1251
CURVE 3 (cont.)	
560	0.1791
618	0.2208
699	0.2834
806	0.3640
909	0.4503
1015	0.5422
CURVE 4	
298	0.0028
473	0.0360
673	0.2834
873	0.4380
CURVE 4 (cont.)	
1073	0.6068
1273	0.7860
1473	0.9680
CURVE 5	
103	-0.102
120	-0.096
149	-0.088
179	-0.082
209	-0.050
240	-0.046
271	-0.008
300	0.002
CURVE 6*	
102	-0.10126
120	-0.09576
150	-0.09519
180	-0.08676
210	-0.04817
240	-0.04248
270	-0.00721
300	0.00227

DATA TABLE 45. COEFFICIENT OF THERMAL LINEAR EXPANSION OF ERBIUM OXIDE Er_2O_3

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3*	
305	6.32
398	6.63
480	6.90
560	7.16
618	7.36
699	7.64
806	8.01
909	8.38
1015	8.76

*Not shown in figure.

SPECIFICATION TABLE 46. THERMAL LINEAR EXPANSION OF EUROPIUM MONOXIDE EuO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	*Composition (weight percent), Specifications, and Remarks*
1*	98	Argyle, B.E., Miyata, N., and Schultz, T.D.	1967	S	25-250		Single crystal; disk specimen 5.0 mm diameter, 0.67 mm thick; cut ultrasonically from crystal having (100) natural cleavage face; data on coefficient of thermal linear expansion also tabulated.

DATA TABLE 46. THERMAL LINEAR EXPANSION OF EUROPIUM MONOXIDE EuO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 1 (cont.)*	
30	-0.337	240	-0.061
40	-0.328	273	-0.027
60	-0.298	293	0.000
80	-0.264		
100	-0.242		
120	-0.220		
140	-0.197		
170	-0.161		
210	-0.109		

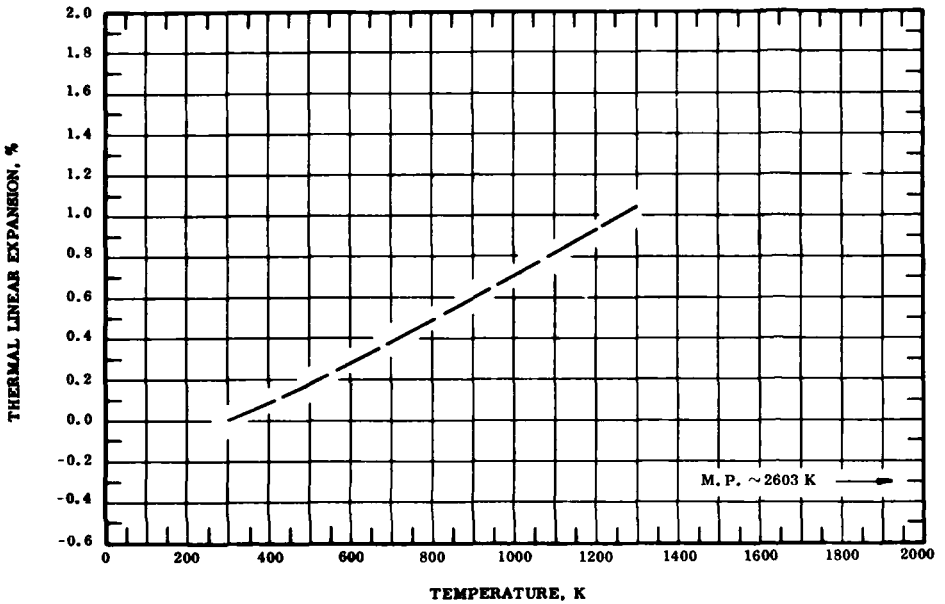
DATA TABLE 46. COEFFICIENT OF THERMAL LINEAR EXPANSION OF EUROPIUM MONOXIDE EuO

[*Temperature*, T, K; *Coefficient of Expansion*, α, 10^{-6} K^{-1}]

T	α	T	α	T	α
CURVE 1*		CURVE 1 (cont.)*		CURVE 1 (cont.)*	
25	*6.0*	72	14.3	173	12.8
28	7.0	75	12.7	200	13.0
42	11.6	80	11.7	225	13.3
54	15.8	89	11.1	250	13.5
62	19.7	98	11.0		
66	22.7	113	11.5		
70	27.5	132	12.0		
70	20.0	152	12.4		

* No figure given.

FIGURE AND TABLE NO. 47R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF EUROPIUM OXIDE Eu_2O_3



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	8.8
400	0.096	9.2
500	0.190	9.5
600	0.287	9.9
700	0.387	10.2
800	0.491	10.5
900	0.597	10.8
1000	0.706	11.0
1100	0.818	11.2
1200	0.931	11.4
1300	1.046	11.6

REMARKS

The provisional values are based on the data reported in curves 2 to 5 and are considered accurate to within ±7%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.238 + 7.473 \times 10^{-4}\ T + 2.364 \times 10^{-7}\ T^2 - 3.926 \times 10^{-11}\ T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

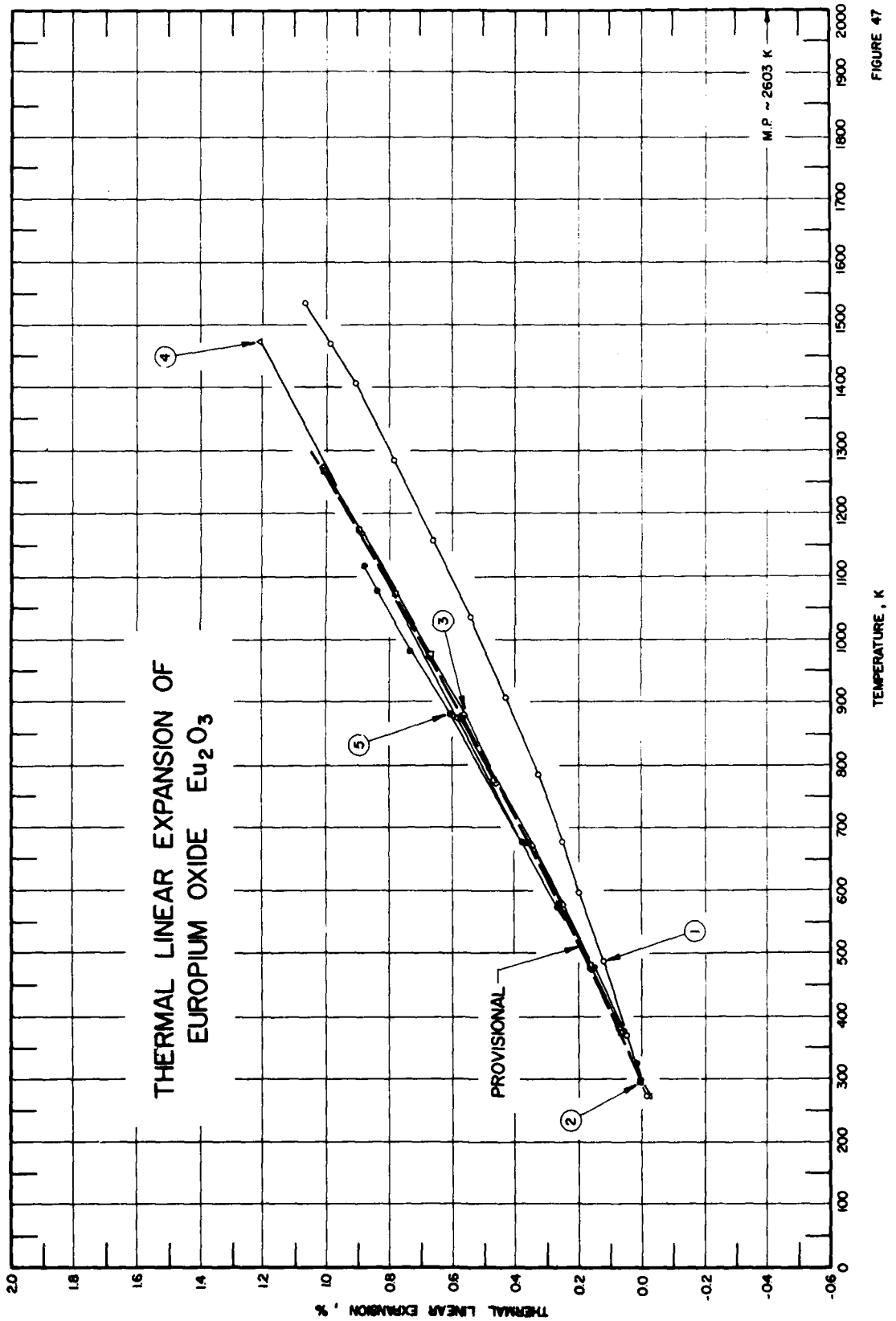

THERMAL LINEAR EXPANSION OF
EUROPIUM OXIDE Eu_2O_3
PROVISIONAL
M.P. ~ 2603 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
4
5

FIGURE 47

SPECIFICATION TABLE 47. THERMAL LINEAR EXPANSION OF EUROPIUM OXIDE Eu_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	68	Stecuro, S. and Campbell, W.J.	1961	X	273-1534		99.9 pure of cubic phase specimen; supplied by Lindsay Chemical Co.; sintered at 1273 K for 16 hr, packed into alumina holder, sintered at 1333 K for 16 hr, cooled to 573 K, stored in vacuum, reported error ±2%; unit cell parameter reported at 273 K is 10.8245 Å; zero-point correction of -0.012% determined by graphical interpolation.
2	14	Wilfong, R.L., Domingues, L.P., Furlong, L.R., and Finlay Son, J.A.	1963	I	298-1270		0.03-0.3 Sm, 0.003-0.03 Ca, 0.001-0.01 Al, Si, 0.0003-0.003 Fe, Mg, V; powder calcinated at 1473 K for 1 hr; mixed with binder (2% varsal plus 2% paraffin dissolved into benzene), hot pressed at 2600 psi to 1673 K ground into shape matured at 1723 K for 1 hr; reground, heated to 1723 K for 1 hr; and desicated; mono-clinic; bulk density 6.5 g cm^{-3} after expansion test by mercury displacement at low pressure; heating rate 5 C per min; zero-point correction of 0.0050% determined by graphical extrapolation.
3	14	Wilfong, R.L., et al.	1963	I	298-1271		The above specimen; expansion measured with increasing temperature on second test; zero-point correction of 0.0050% determined by graphical extrapolation.
4	101	Curtis, C.E. and Tharp, A.G.	1959	L	273-1473		Dry pressed mixture of 21% powder (calcined at 1173 K for 10-12 hr) and 79% powder (pre-calcined at 1573 K for 3 hr) into bar without binder or lubricant at 13,720 psi; fired at 1773 K for 2 hr, machined into rod specimen of mono-clinic form; heating rate 3 C per min.
5	87	Ploetz, G.L., Krystyniak, C.W., and Dumes, H.E.	1957	I	322-1118		Conical specimen; cut from hot pressed sample in monoclinic region; 95% theo-retical density; zero-point correction of 0.008% determined by graphical extrapolation.

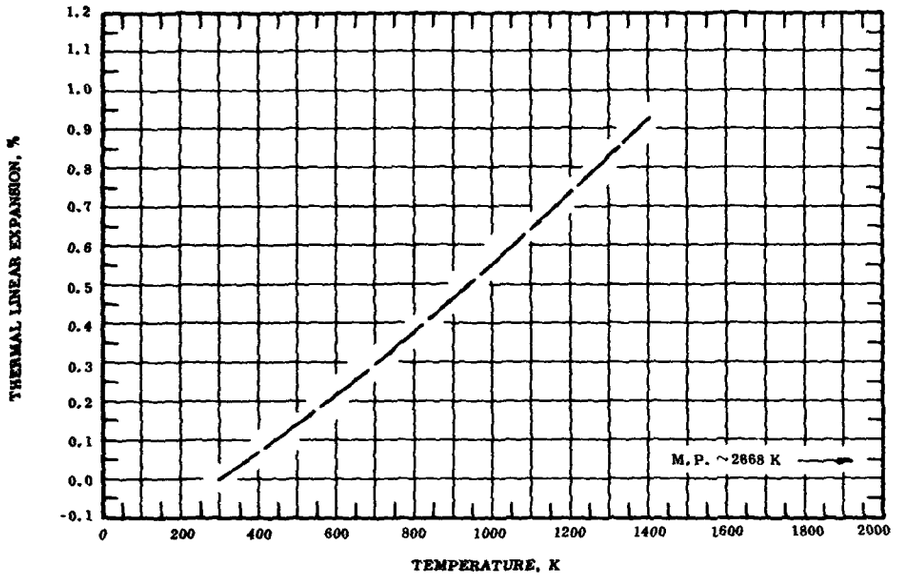
DATA TABLE 47. THERMAL LINEAR EXPANSION OF EUROPIUM OXIDE Eu_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3		CURVE 4	
273	-0.012	[illegible]	0.005	298	0.005*	273	-0.020
299	0.003	3	0.070	379	0.074	873	0.586
370	0.052	479	0.168	474	0.164	1473	1.215
484	0.124	576	0.263	576	0.262		
597	0.200	674	0.362	671	0.358	CURVE 5	
676	0.258	777	0.467	774	0.464		
785	0.337	873	0.569	875	0.571	322	0.025
908	0.432	974	0.678	972	0.676	372	0.068
1032	0.545	1073	0.788	1073	0.788*	475	0.166
1160	0.663	1172	0.899	1171	0.898	572	0.275
1284	0.783	1270	1.010	1271	1.012	678	0.380
1402	0.908					880	0.610
1470	0.986					980	0.740
1534	1.066					1079	0.840
						1118	0.881

* Not shown in figure.

FIGURE AND TABLE NO. 48R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF *GADOLINIUM OXIDE* Gd_2O_3



PROVISIONAL VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

T	$\Delta L/L_0$	α
293	0.000	6.6
400	0.072	7.0
500	0.144	7.3
600	0.219	7.7
700	0.297	8.0
800	0.379	8.3
900	0.464	8.6
1000	0.552	8.9
1100	0.642	9.2
1200	0.736	9.5
1300	0.832	9.7
1400	0.930	10.0

REMARKS

The provisional values are considered accurate to within ± 15% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.176 + 5.397 \times 10^{-4} T + 2.091 \times 10^{-7} T^2 - 2.169 \times 10^{-11} T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ± 15%.

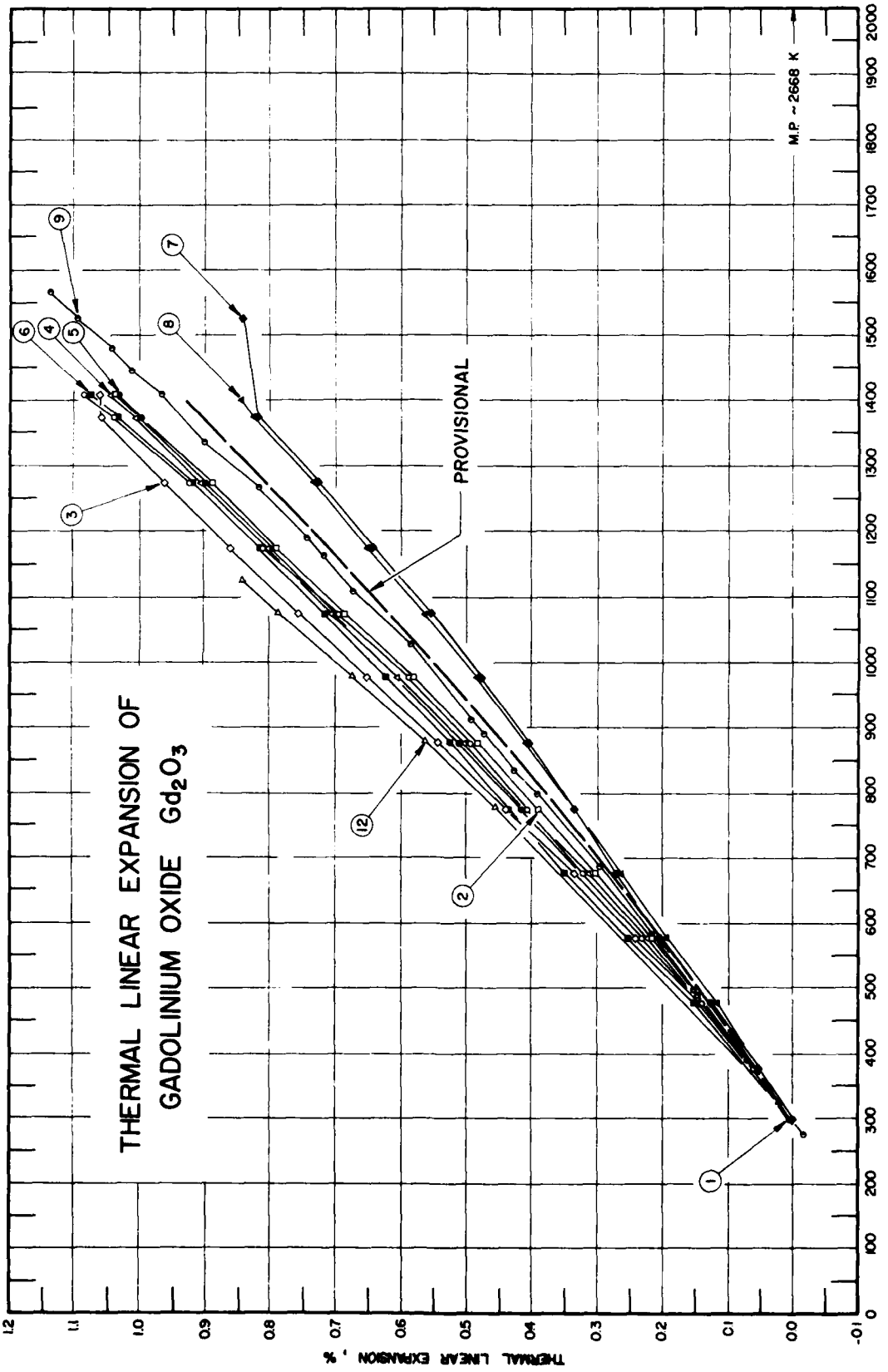

THERMAL LINEAR EXPANSION OF
GADOLINIUM OXIDE Gd_2O_3
PROVISIONAL
M.P. ~2668 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-.01
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
4
5
6
7
8
9
12

FIGURE 48

SPECIFICATION TABLE 48. THERMAL LINEAR EXPANSION OF GADOLINIUM OXIDE Gd_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	143	Stacy, D.W.	1967	L	298-1408	Monoclinic Gd_2O_3-1	0.08 Eu, 0.02 Sm, 0.02 Ta. ≤0.01 Tb, 0.01 Y, 0.003 Ca, ≤0.001 each Al, Cr, Cu, Fe, Lu, Nd, and Si; specimen 0.125 x 0.25 x 1.0 in., made by pressing powder in steel die to 1000 psi, inverted and repressed to 1200 psi, and repressed to 50 000 psi in isostatic press; fired at 1973 K in vacuum; 81.3% of theoretical density; zero-point correction of 0.004% determined by graphical extrapolation.
2	143	Stacy, D.W.	1967	L	298-1408	Monoclinic Gd_2O_3-2	Similar to the above specimen except fired at 1573 K for 18.5 hr in air atm; 63.0% of theoretical density; zero-point correction of 0.004% determined by graphical extrapolation.
3	143	Stacy, D.W.	1967	L	298-1408	Monoclinic Gd_2O_3-3	Similar to the above specimen except fired at 2273 K in reducing atmosphere; 85.1% of theoretical density; zero-point correction of 0.004% determined by graphical extrapolation.
4	143	Stacy, D.W.	1967	L	298-1408	Monoclinic Gd_2O_3-4	Similar to the above specimen except fired at 1573 K for 45 min. in air atmosphere; 63.6% of theoretical density; zero-point correction of 0.004% determined by graphical extrapolation.
5	143	Stacy, D.W.	1967	L	298-1408	Monoclinic Gd_2O_3-5	Similar to the above specimen except fired at 1573 K for 45 min. in air atmosphere; 63.4% of theoretical density; zero-point correction of 0.004% determined by graphical extrapolation.
6	143	Stacy, D.W.	1967	L	298-1408	Monoclinic Gd_2O_3-6	Similar to the above specimen except fired at 2173 K in reducing atmosphere; 87.3% of theoretical density; zero-point correction of 0.004% determined by graphical extrapolation.
7	143	Stacy, D.W.	1967	L	298-1523	Cubic Gd_2O_3-7	Similar to the above specimen except fired at 1473 K for 18 hr in air atmosphere; 67.2% of theoretical density; zero-point correction of 0.003% determined by graphical extrapolation.
8	143	Stacy, D.W.	1967	L	298-1398	Cubic Gd_2O_3-8	Similar to the above specimen except fired at 1473 K for 18 hr in air atmosphere; 67% of theoretical density; zero-point correction of 0.003% determined by graphical extrapolation.
9	68	Stecura, S. and Campbell, W.J.	1961	X	273-1568		99.9 pure specimen; supplied by Michigan Chemical Co.; sintered at 1423 K for 24 hr; packed into alumina holder, sintered at 1423 K for 12 hr, cooled at 623 K and stored in vacuum; reported error ±2%; zero-point correction of -0.015% determined by graphical interpolation; cubic phase.
10*	102	Sawbridge, P.T. and Waterman, N.A.	1968	X	293, 1173		Monoclinic crystal; specimen 0.5 cm diameter, 0.003 cm thick; made from oxidized disc Gd metal; annealed in argon atmosphere at 1873 K for 1 hr; expansion measured along [100].
11*	102	Sawbridge, P.T. and Waterman, N.A.	1968	X	293, 1173		The above specimen; expansion measured along [001].
12	87	Ploetz, G.L., Krystyniak, C.W., and Dumas, H.E.	1957	I	322-1124		Conical specimen about 4.7 mm high cut from pellets which made from pure oxide hot-pressed in graphite molds into 0.165 in O.D., 0.75 in. long; 95% of theoretical density; zero-point correction of 0.006% determined by graphical extrapolation.
13*	500	Rudenko, V.S. and Boganov, A.G.	1970	X	287-1607		Cubic modification specimen; structure transition from cubic to monoclinic at 1613 K; volume at 293 K is 0.131 cm^3/g, at 1613 K is 0.135 cm^3/g; lattice parameter 10.809 Å at 293 K.

*Not shown in figure.

DATA TABLE 48. THERMAL LINEAR EXPANSION OF GADOLINIUM OXIDE Gd_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
298	0.004
373	0.063
473	0.141
573	0.232
673	0.322
773	0.409
873	0.493
973	0.590
1073	0.699
1173	0.812
1273	0.925
1373	1.040
1408	1.085

CURVE 2

T	$\Delta L/L_0$
298	0.004*
373	0.060
473	0.144
573	0.219
673	0.303
773	0.390
873	0.482
973	0.583
1073	0.688
1173	0.791
1273	0.889
1373	1.000
1408	1.039

CURVE 3

T	$\Delta L/L_0$
298	0.004*
373	0.064
473	0.149
573	0.242
673	0.336
773	0.440
873	0.547
973	0.654
1073	0.760
1173	0.863
1273	0.962
1373	1.060
1408	1.062

CURVE 4

T	$\Delta L/L_0$
298	0.004*
373	0.064*
473	0.144*
573	0.225
673	0.316
773	0.410
873	0.504
973	0.607
1073	0.706
1173	0.808
1273	0.908
1373	1.009
1408	1.043

CURVE 5

T	$\Delta L/L_0$
298	0.004*
373	0.061*
473	0.142*
573	0.229*
673	0.321*
773	0.416
873	0.511
973	0.607*
1073	0.705
1173	0.804
1273	0.900
1373	0.999
1408	1.032

CURVE 6

T	$\Delta L/L_0$
298	0.004*
373	0.065*
473	0.154
573	0.253
673	0.350
773	0.438
873	0.526
973	0.621
1073	0.717
1173	0.817
1273	0.920
1373	1.035
1408	1.077

CURVE 7

T	$\Delta L/L_0$
298	0.003
373	0.055
473	0.128
573	0.204
673	0.273
773	0.336
873	0.403
973	0.478
1073	0.557
1173	0.641
1273	0.726
1373	0.820
1523	0.842

CURVE 8

T	$\Delta L/L_0$
298	0.003*
373	0.051
473	0.120
573	0.196
673	0.269
773	0.336*
873	0.406
973	0.484
1073	0.566
1173	0.650
1273	0.731
1373	0.822
1398	0.845

CURVE 9

T	$\Delta L/L_0$
273	-0.15
299	0.005*
386	0.072
485	0.148
491	0.155
577	0.219
681	0.296
799	0.391
831	0.427
889	0.473
910	0.492
1025	0.586
1107	0.675

CURVE 9 (cont.)

T	$\Delta L/L_0$
1161	0.718
1189	0.746
1267	0.819
1335	0.901
1408	0.966
1448	1.014
1480	1.044
1524	1.091
1568	1.138

CURVE 10*

T	$\Delta L/L_0$
293	0.000
1173	0.872

CURVE 11*

T	$\Delta L/L_0$
293	0.000
1173	1.041

CURVE 12

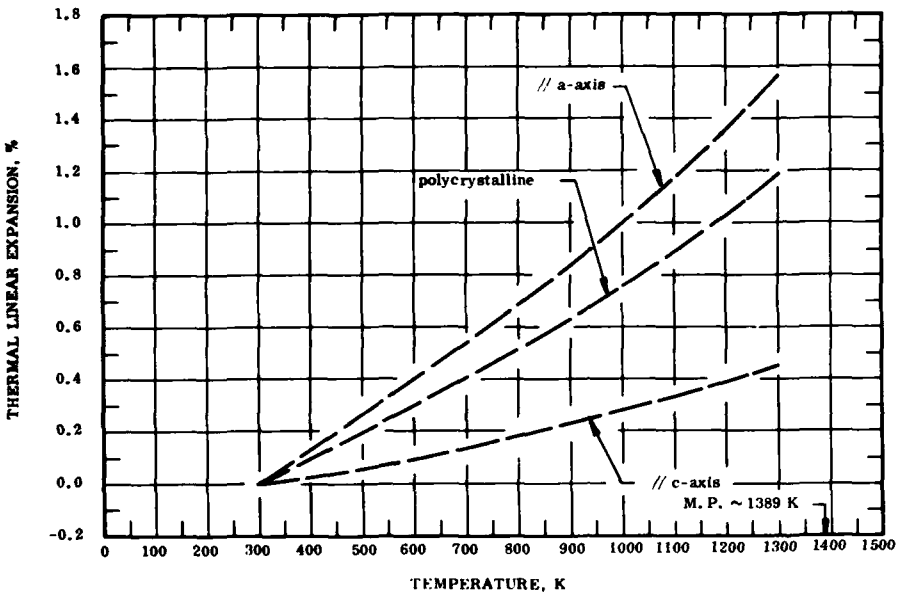
T	$\Delta L/L_0$
322	0.023
372	0.066*
473	0.150*
574	0.249*
676	0.344
777	0.457
876	0.565
977	0.675
1078	0.789
1124	0.843

CURVE 13*

T	$\Delta L/L_0$
287	-0.074
293	0.000
305	0.009
306	0.065
881	0.518
1323	0.814
1607	1.175

*Not shown in figure.

FIGURE AND TABLE NO. 49R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GERMANIUM DIOXIDE (QUARTZ TYPE) GeO_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, $10^{-6}\ K^{-1}$]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	9.3
400	0.028	0.136	0.101	9.6
500	0.061	0.266	0.199	10.0
600	0.099	0.401	0.301	10.4
700	0.142	0.540	0.408	10.9
800	0.188	0.687	0.520	11.5
900	0.238	0.841	0.639	12.2
1000	0.289	1.005	0.764	12.9
1100	0.342	1.178	0.898	13.8
1200	0.396	1.363	1.040	14.7
1300	0.450	1.561	1.191	15.6

REMARKS

The provisional values for the axial thermal expansion are based on data reported in curves 1 and 7 for // a-axis and curves 2 and 8 for //c-axis. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ± 7% and are represented approximately by the following equations:

$$\underline{//\ c\text{-axis}}: \quad \Delta L/L_0 = -0.346 - 5.309 \times 10^{-6}\, T + 4.588 \times 10^{-7}\, T^2 - 1.298 \times 10^{-10}\, T^3$$

$$\underline{//\ a\text{-axis}}: \quad \Delta L/L_0 = -0.366 + 1.254 \times 10^{-2}\, T - 8.008 \times 10^{-6}\, T^2 + 1.963 \times 10^{-10}\, T^3$$

$$\underline{\text{polycrystalline}}: \quad \Delta L/L_0 = -0.266 + 8.944 \times 10^{-4}\, T + 7.934 \times 10^{-6}\, T^2 + 1.278 \times 10^{-10}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

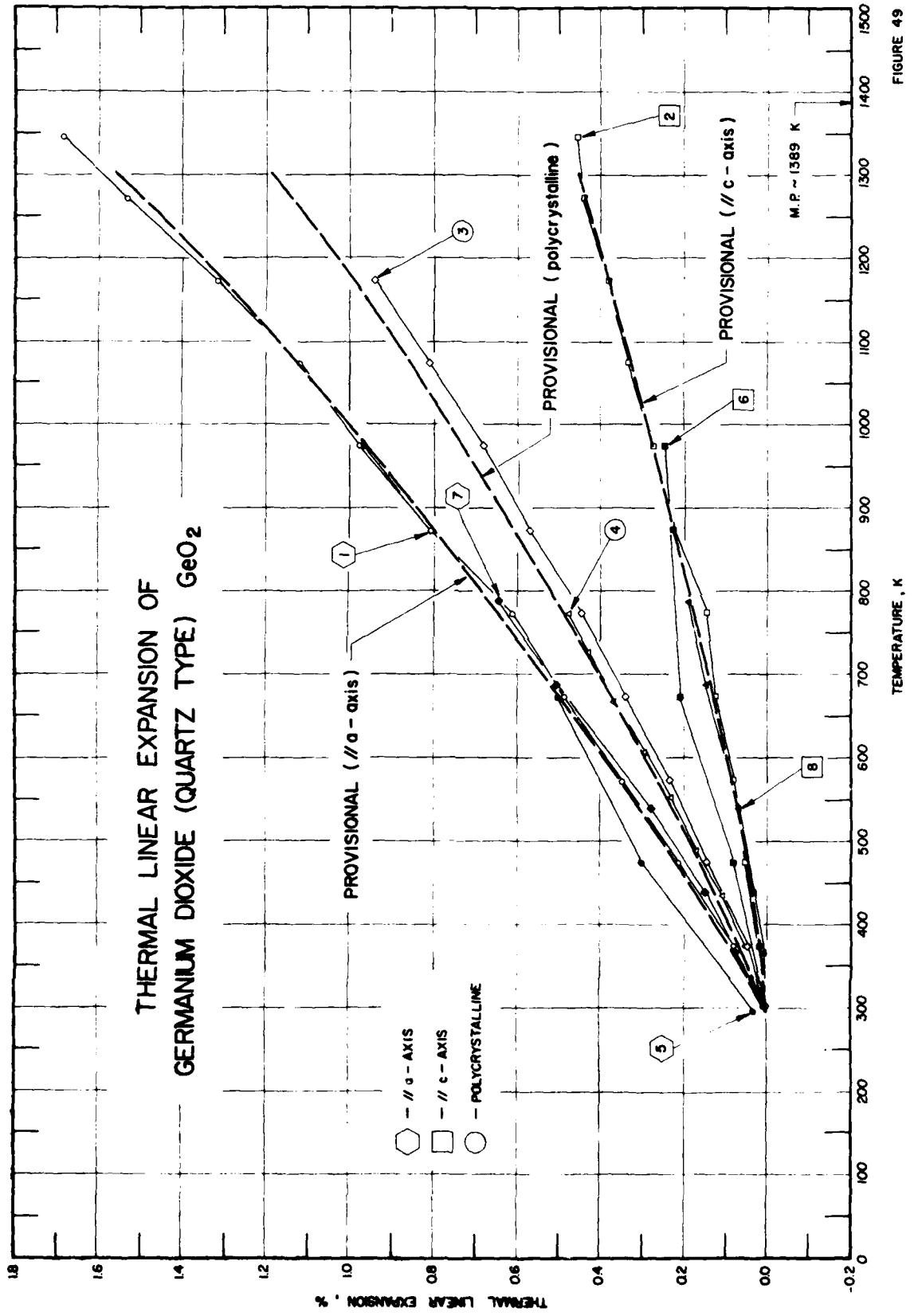

THERMAL LINEAR EXPANSION OF
GERMANIUM DIOXIDE (QUARTZ TYPE) GeO_2
PROVISIONAL (// a - axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// c - axis)
M.P. ~ 1389 K
// a - AXIS
// c - AXIS
POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 49

SPECIFICATION TABLE 49. THERMAL LINEAR EXPANSION OF GERMANIUM DIOXIDE (QUARTZ TYPE) GeO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	107	Sarver, J. F.	1961	X	303-1348		Specimen sintered at 1373 K for 24 hr; expansion measured along a-axis; zero-point correction of 0.006% determined by graphical extrapolation.
2	107	Sarver, J. F.	1961	X	303-1348		Same as the above specimen; expansion measured along c-axis; zero-point correction of 0.005% determined by graphical extrapolation.
3	107	Sarver, J. F.	1961	L	303-1173		Aggregated specimen; 10 cm long; sintered at 1373 K for 24 hr; heating rate 2 C per min; zero-point correction of 0.004% determined by graphical extrapolation.
4	106	Murthy, K. M.	1962	L	323-773		Bar specimen; 1.0 x 1.0 x 10.0 cm; obtained from Eagle-Picher Co.; pressed in steel mold and sintered at 1073 K; heating rate 3 C per min; zero-point correction of 0.002% determined by graphical extrapolation.
5	344	Majumdar, A.J. and Roy, R.	1965	X	298-973		Spectrographic quality; melted and powdered; expansion measured along a-axis; unit cell parameter reported at 198 K is 4.987 Å; 4.985 Å at 293 K determined by graphical extrapolation.
6	344	Majumdar, A.J. and Roy, R.	1965	X	298-973		Spectrographic quality; melted and powdered; expansion measured along c-axis; unit cell parameter reported at 298 K is 5.628 Å; 5.648 Å at 293 K used for data conversion.
7	595	Rao, K. V. K., Naidu, S. V. N., and Iyengar, L.	1972	X	309-789		Sample of hexagonal GeO_2 from Dr. F. Dachille, Pennsylvania State Univ.; error in temperature measured ±2 C; standard error in lattice parameter 0.0002 Å in the a parameter; 4.9853 Å reported at 309 K; 4.9850 Å at 298 K determined by graphical extrapolation; data on the coefficient of thermal linear expansion also reported.
8	595	Rao, K. V. K., et al.	1972	X	309-789		Same as the above specimen; standard error in c-lattice parameter 0.0001 Å; 5.6481 Å reported at 309 K; 5.6480 Å at 298 K determined by graphical extrapolation; data on the coefficient of thermal linear expansion also reported.

DATA TABLE 49. THERMAL LINEAR EXPANSION OF GERMANIUM DIOXIDE (QUARTZ TYPE) GeO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
303	0.009
373	0.089
473	0.224
573	0.354
673	0.494
773	0.619
873	0.814
973	0.979
1073	1.129
1173	1.324
1273	1.544
1348	1.694
CURVE 2	
303	0.005
373	0.025
473	0.055
CURVE 2 (cont.)	
573	0.085
673	0.125
773	0.145
873	0.225
973	0.275
1073	0.330
1173	0.380
1273	0.435
1348	0.450
CURVE 3	
303	0.004*
373	0.054
473	0.144
573	0.235
673	0.340
773	0.445
CURVE 3 (cont.)	
873	0.565
973	0.680
1073	0.810
1173	0.940
CURVE 4	
323	0.017
373	0.057
433	0.112
488	0.172
553	0.232
607	0.297
668	0.362
727	0.427
773	0.477
CURVE 5	
298	0.040
473	0.301
673	0.502
873	0.802*
973	0.963
CURVE 6	
298	-0.354*
473	0.089
673	0.213
873	0.213*
973	0.248
CURVE 7	
309	0.0060*
369	0.0802
CURVE 7 (cont.)	
438	0.1525
540	0.2808
688	0.5015
789	0.6479
CURVE 8	
309	0.0018*
369	0.0106
438	0.0372
540	0.0744
688	0.1470
789	0.1965

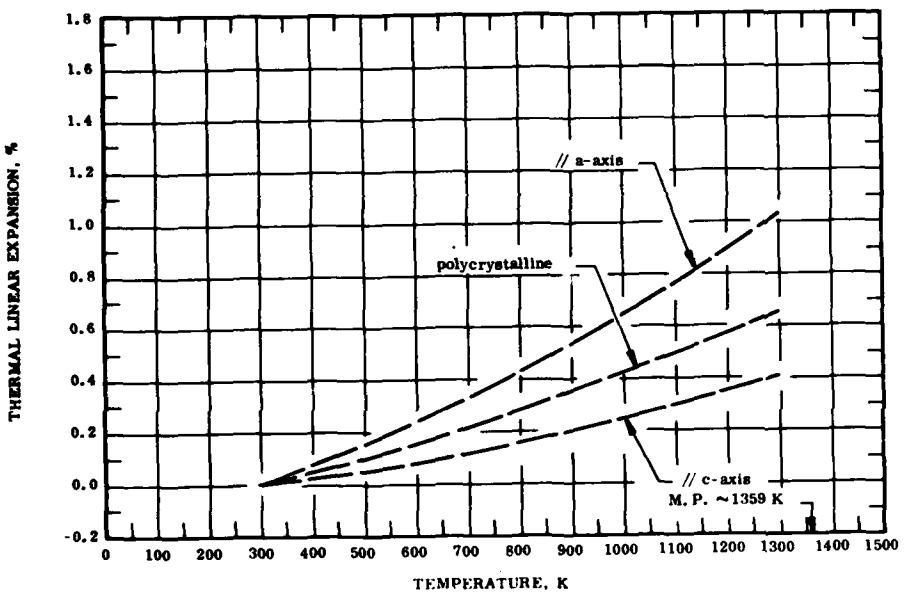
DATA TABLE 49. COEFFICIENT OF THERMAL LINEAR EXPANSION OF GERMANIUM DIOXIDE (QUARTZ TYPE) GeO_2

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 7*	
324	11.3
363	11.5
405	11.6
445	11.7
483	12.4
525	13.0
565	13.8
604	14.5
644	15.0
684	15.2
724	15.5
763	16.1
CURVE 8*	
323	1.9
365	2.4
CURVE 8 (cont.)*	
403	2.9
443	3.2
484	3.7
523	4.0
563	4.4
603	4.7
644	4.9
684	5.0
724	5.3
764	5.6

* Not shown in figure.

FIGURE AND TABLE NO. 50R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GERMANIUM DIOXIDE (RUTILE TYPE) GeO_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	4.5
400	0.021	0.078	0.051	5.0
500	0.048	0.157	0.102	5.4
600	0.081	0.242	0.159	5.8
700	0.119	0.333	0.219	6.2
800	0.162	0.431	0.283	6.6
900	0.207	0.535	0.351	6.9
1000	0.260	0.647	0.422	7.3
1100	0.304	0.767	0.496	7.6
1200	0.353	0.893	0.574	7.9
1300	0.401	1.028	0.654	8.2

REMARKS

The provisional values for the axial thermal expansion are based on the data reported in curves 1 and 3 for //a-axis and curves 2 and 4 for //c-axis. These values for the polycrystalline sample are based on the data reported in curves 5 and 6. These values are considered accurate to within ±7% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -0.635 - 1.255 \times 10^{-4} T + 5.504 \times 10^{-7} T^2 - 1.636 \times 10^{-10} T^3$

// a-axis: $\Delta L/L_0 = -0.182 + 5.467 \times 10^{-4} T + 2.381 \times 10^{-7} T^2 + 4.414 \times 10^{-11} T^3$

polycrystalline: $\Delta L/L_0 = -0.110 + 3.025 \times 10^{-4} T + 2.630 \times 10^{-7} T^2 - 3.344 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

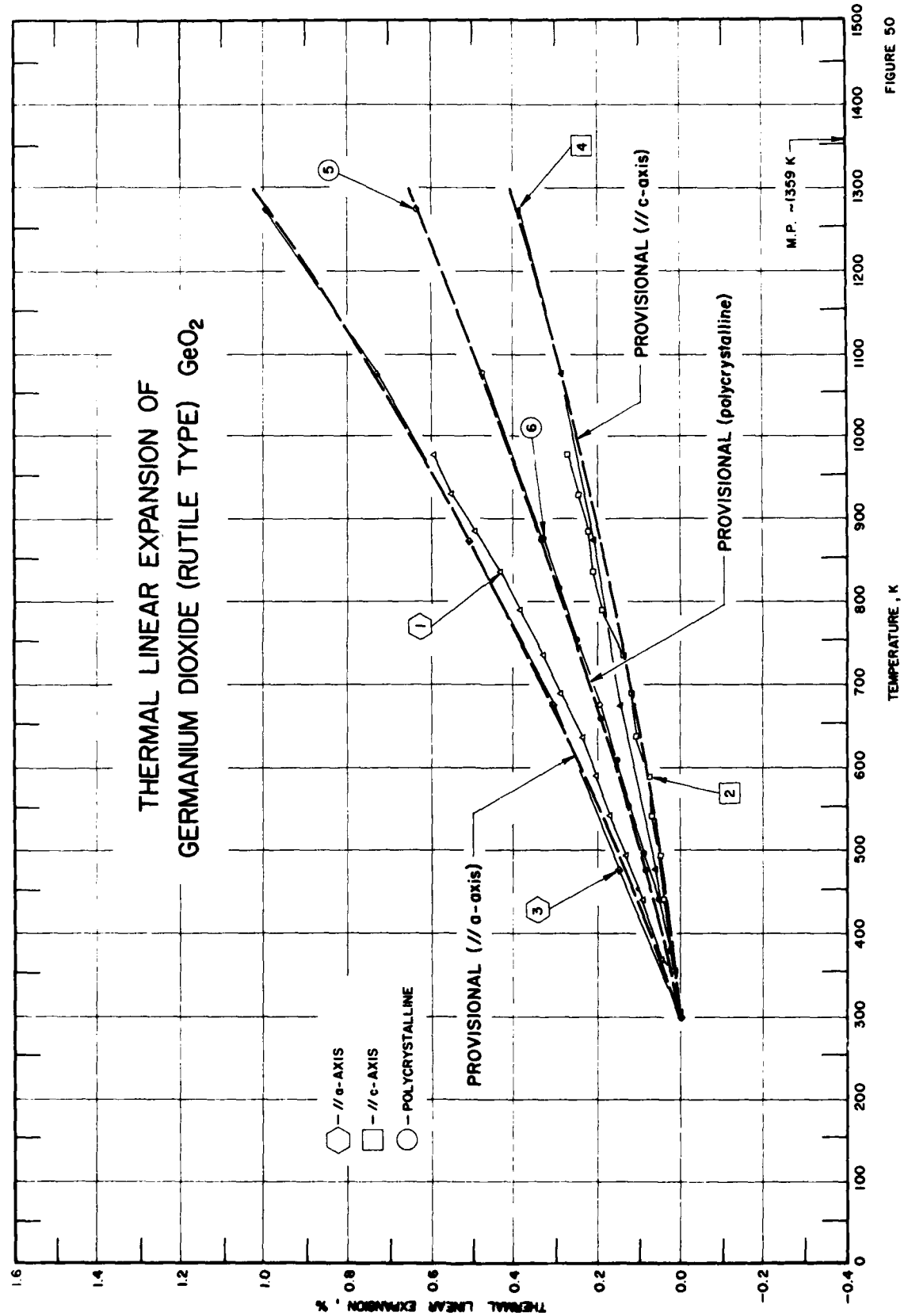

THERMAL LINEAR EXPANSION OF
GERMANIUM DIOXIDE (RUTILE TYPE) GeO_2
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
M.P. ~1359 K
PROVISIONAL (// c-axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// a-axis)
⬡ – // a-AXIS
□ – // c-AXIS
○ – POLYCRYSTALLINE
1
2
3
4
5
6

FIGURE 50

SPECIFICATION TABLE 50. THERMAL LINEAR EXPANSION OF GERMANIUM DIOXIDE (RUTILE TYPE) GeO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	104	Rao, K.V.K., Nagender Naidu, S.V., and Iyengar, L.	1968	X	301-975		Specimen prepared by heating hexagonal GeO_2 at 1073 K for 20 hr, filling quartz capillary with powder; lattice constant determined from reflections from 213, 422, 303, and 512 planes; expansion measured along a-axis with CuKα radiation; lattice constant reported at 301.2 K is 4.3975 Å; 4.3973 Å at 293.2 K determined by graphical extrapolation.
2	104	Rao, K.V.K., et al.	1968	X	301-975		The above specimen; expansion measured along c-axis; lattice constant reported at 301.2 K is 2.8625 Å; 2.8624 Å at 293.2 K determined by graphical extrapolation.
3	105	Sarver, J.F.	1963	X	298-1273		Bar specimen; prepared by hydrothermal treatment of commercial GeO_2 of α-quartz structure; stable below about 1323 K, above which temperature it inverts slowly to quartz modification which melts at 1389 K; expansion measured along a-axis; lattice constant reported at room temperature is 4.398 Å; *zero-point correction of 0.005% determined by graphical extrapolation.*
4	105	Sarver, J.F.	1963	X	298-1273		Same as the above specimen; expansion measured along c-axis; lattice constant reported at room temperature is 2.862 Å; zero-point correction of 0.001% determined by graphical extrapolation.
5	105	Sarver, J.F.	1963	L	298-1273		Aggregate specimen 2.0 x 1.0 x 10.0 cm; prepared from hydrothermal treatment of commercial GeO_2 with α-quartz structure; fired at 1273 K for 24 hr; zero-point correction of 0.002% determined by graphical extrapolation.
6	106	Murthy, M.K.	1962	L	378-873		Tetragonal aggregated bar specimen; 1.0 x 1.0 x 10.0 cm; supplied by Eagle-Picher Co.; prepared by pressing powder in steel mold and sintering at 1073 K; *heating rate 3 C per min; zero-point correction of 0.001% determined by* graphical extrapolation.
7*	344	Majumdar, A.J. and Roy, R.	1965	X	299-873		Spectrographic quality; melted and powdered; expansion measured along a-axis; unit cell parameter reported at 299.40 K is 4.404 Å; 4.403 Å at 293 K determined by graphical extrapolation.
8*	344	Majumdar, A.J. and Roy, R.	1965	X	299-873		Spectrographic quality; melted and powdered; expansion measured along c-axis; unit cell parameter reported at 299.40 K is 2.870 Å; 2.870 Å at 293 K used for data conversion.

* Not shown in figure.

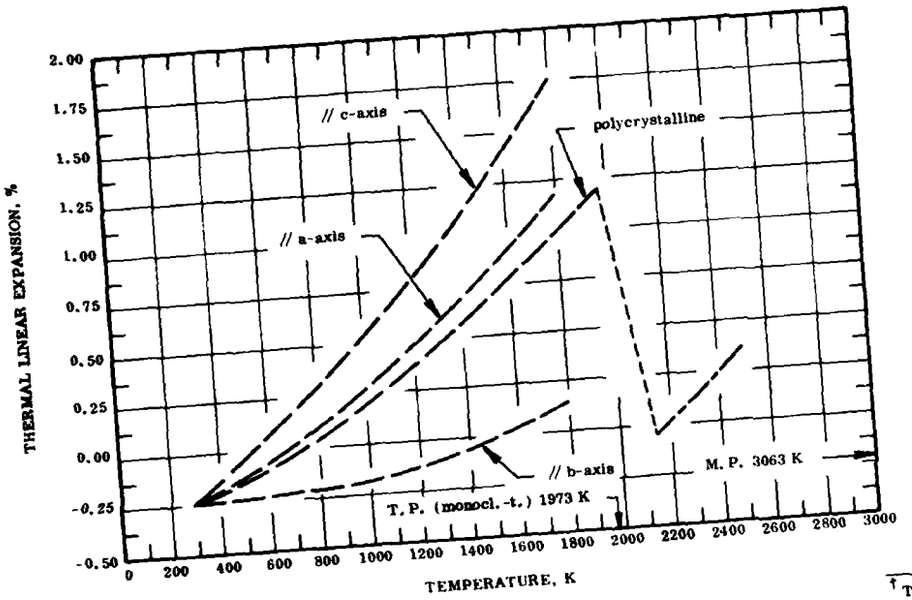
DATA TABLE 50. THERMAL LINEAR EXPANSION OF GERMANIUM DIOXIDE (RUTILE TYPE) GeO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
301	0.0045
351	0.0250
369	0.0477
438	0.0909
490	0.1364
540	0.1682
588	0.2023
634	0.2387
688	0.2865
734	0.3297
789	0.3820
836	0.4389
881	0.4957
928	0.5435
975	0.5935
CURVE 2	
301	0.0034*
351	0.0209
369	0.0244*
438	0.0419
490	0.0524
540	0.0698
588	0.0768
634	0.1083
688	0.1187
734	0.1397
789	0.1816
836	0.2131
881	0.2200
928	0.2410
975	0.2759
CURVE 3	
298	0.005
473	0.145
673	0.305
873	0.505
1073	0.735
1273	0.990
CURVE 4	
298	0.001*
473	0.061
673	0.141
873	0.211
1073	0.281
1273	0.381
CURVE 5	
298	0.002*
473	0.082
673	0.197
873	0.332
1073	0.477
1273	0.637
CURVE 6	
378	0.026
439	0.056
493	0.086
551	0.121
608	0.156
659	0.195
753	0.250
814	0.290
873	0.324
CURVE 7*	
299.40	0.023
473	0.068
673	0.318
873	0.477
CURVE 8*	
299.40	0.000
473	0.209
673	0.383
873	0.627

* Not shown in figure.

FIGURE AND TABLE NO. 51R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF HAFNIUM DIOXIDE HfO_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	// b-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	0.000	3.8
400	0.115	0.058	0.008	0.051	4.6
500	0.220	0.117	0.014	0.104	5.4
600	0.322	0.185	0.020	0.160	6.1
700	0.433	0.262	0.028	0.224	6.7
800	0.545	0.342	0.037	0.292	7.3
900	0.660	0.429	0.050	0.366	7.9
1000	0.780	0.521	0.069	0.446	8.4
1100	0.908	0.620	0.093	0.533	8.9
1200	1.040	0.720	0.117	0.623	9.3
1300	1.184	0.826	0.150	0.721	9.7
1400	1.334	0.935	0.185	0.823	10.0
1500	1.495	1.050	0.225	0.922	10.3
1600	1.660	1.150	0.275	1.037	10.6
1700	1.826	1.255	0.330	1.133	10.8
1800	2.010	1.370	0.393	1.245	10.9
1900				1.352	11.1
1973†				1.433	11.2
2140				0.200	
2200				0.265	
2300				0.380	
2400				0.500	
2500				0.610	

† Transition temperature at 1973 K.

REMARKS

The provisional values of the axial thermal expansion are based on the data reported in curves 5, 23 and 28 for //a-axis, curves 6, 24, 29 and 32 for //b-axis and curves 7, 30 and 33 for //c-axis. The values for the polycrystalline sample are calculated from the axial values at temperatures below transition temperature and are based on the data reported in curve 14 at temperatures above transition temperature. This result is recommended in preference to the reported experimental data for polycrystalline samples on the suspicion that those samples exhibit preferential orientation and are not randomly oriented. These values are considered accurate to within ± 7% at temperatures below 1973 K and ±20% above 1973 K and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -0.276 + 9.525 \times 10^{-4}\,T + 1.884 \times 10^{-6}\,T^2 + 8.758 \times 10^{-11}\,T^3$ (293-1800 K)

// a-axis: $\Delta L/L_0 = -0.086 + 1.392 \times 10^{-4}\,T + 5.936 \times 10^{-7}\,T^2 - 1.235 \times 10^{-10}\,T^3$ (293-1800 K)

// b-axis: $\Delta L/L_0 = -0.007 + 4.425 \times 10^{-5}\,T - 4.885 \times 10^{-8}\,T^2 + 8.213 \times 10^{-11}\,T^3$ (293-1800 K)

polycrystalline: $\Delta L/L_0 = -0.070 + 1.268 \times 10^{-4}\,T + 4.658 \times 10^{-7}\,T^2 - 7.289 \times 10^{-11}\,T^3$ (293-1973 K)

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

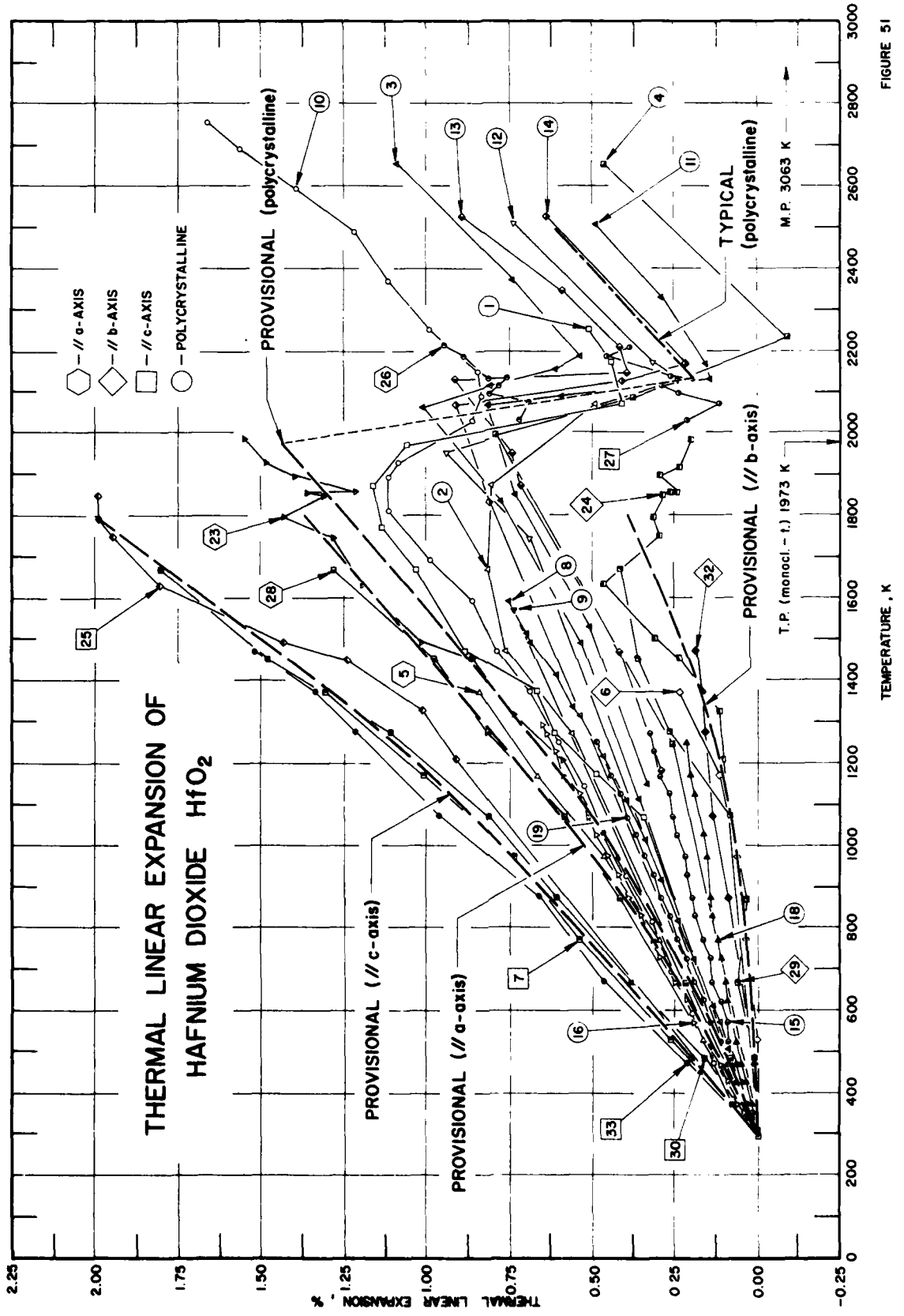

THERMAL LINEAR EXPANSION OF
HAFNIUM DIOXIDE HfO2
// a-AXIS
// b-AXIS
// c-AXIS
POLYCRYSTALLINE
PROVISIONAL (polycrystalline)
TYPICAL
(polycrystalline)
M.P. 3063 K
PROVISIONAL (// b-axis)
T.P. (monocl. - t.) 1973 K
PROVISIONAL (// c-axis)
PROVISIONAL (// a-axis)
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000

FIGURE 51

SPECIFICATION TABLE 51. THERMAL LINEAR EXPANSION OF HAFNIUM DIOXIDE HfO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	108	Rausch, J.J.	1966		296-2255		Monoclinic crystal specimen; sprayed with plasma onto mandrel to form layer and mandrel removed.
2	108	Rausch, J.J.	1966		296-2068		The above specimen; expansion measured with decreasing temperature on second test; zero-point correction of 0.147% determined by graphical extrapolation.
3	109	Ohnysty, B., Stausfield, O.M., Stetson, A.R., and Metcalfe, A.G.	1965	T	296-2649		99.90 pure; bar specimen 0.3 x 0.4 x 2.5 in.; obtained from Kleber Laboratories; powder crushed and pressed; zero-point correction of -0.003% determined by graphical extrapolation.
4	109	Ohnysty, B., et al.	1965	T	2650-304		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.642% determined by graphical extrapolation.
5	61	Grain, C.F. and Campbell, W.J.	1962	X	301-1371		99.5 pure; monoclinic specimen; mixed with 30 wt.% platinum powder as internal standard; fired at 1773 K for 24 hr, cooled, ground, and spread on alumina holder; expansion measured along a-axis; zero-point correction of 0.00% determined by graphical extrapolation.
6	61	Grain, C.F. and Campbell, W.J.	1962	X	301-1371		The above specimen; expansion measured along b-axis; zero-point correction of 0.00% determined by graphical extrapolation.
7	61	Grain, C.F. and Campbell, W.J.	1962	X	301-1371		The above specimen; expansion measured along c-axis; zero-point correction of 0.01% determined by graphical extrapolation.
8	72	Fulkerson, S.D.	1960	L	510-1591		Polycrystalline specimen.
9	113	Curtis, C.E., Doney, L.M., and Johnson, J.R.	1954	L	523, 1573	Specimen C Zr-free	0.1 Ti, 0.06 Al, 0.01 Fe, 0.01 Si; specimen 0.375 in. diameter, 1 in. long; prepared by dry-pressing, fired at 1873 K for 2 hr; heating rate 3 C per min; coefficient of thermal linear expansion from 293 K to 523 K is 5.8×10^{-6} K^{-1} assumed by TPRC.
10	114	Ohnysty, B. and Rose, F.K.	1964	T	291-2759		Nuclear grade specimen; obtained from Wah Chang Corp; pressed at 1300 psi, sintered at 1255 K for 1 hr and 2755 K for 1 hr in argon atmosphere.
11	115	Ohnysty, B. and Stetson, A.R.	1963	T	1147-2506	Sample 30-1	99.9 pure spectroscopic grade specimen; 0.76 x 1.02 x 6.35 cm; obtained from Wah Chang Corp; pressed at 1300 psi, sintered at 1255 K for 1 hr and 2755 K for 1 hr in argon atmosphere.
12	115	Ohnysty, B. and Stetson, A.R.	1963	T	2506-310		The above specimen; expansion measured with decreasing temperature; zero-point correction of 0.235% determined by graphical extrapolation.
13	115	Ohnysty, B. and Stetson, A.R.	1963	T	1180-2521		The above specimen; expansion measured with increasing temperature on second test.
14	115	Ohnysty, B. and Stetson, A.R.	1963	T	2521-305		The above specimen; expansion measured with decreasing temperature on second test; zero-point correction of -0.255% determined by graphical extrapolation.
15	116	Stejskal, M., Jenkins, A.L., Gunderson, J.M., Breslich, F.N., Cona, D.A., and Sterry, W.M.	1961	L	350-1273	HfO_2 - I	Specimen fired at 1783 K; zero-point correction of -0.01% determined by graphical extrapolation.
16	116	Stejskal, M., et al.	1961	L	350-1291	HfO_2 - II	Similar to the above specimen; zero-point correction of -0.01% determined by graphical extrapolation.
17*	116	Stejskal, M., et al.	1961	L	350-1282	HfO_2 - III	Similar to the above specimen; zero-point correction of -0.02% determined by graphical extrapolation.

* Not shown in figure.

SPECIFICATION TABLE 51. THERMAL LINEAR EXPANSION OF HAFNIUM DIOXIDE HfO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
18	116	Stejskal, M., et al.	1961	L	350-1243	HfO_2 - IV	Similar to the above specimen; zero-point correction of -0.01% determined by graphical extrapolation.
19	116	Stejskal, M., et al.	1961	L	373-1257	HfO_2 - I	Similar to the above specimen except fired at 2027 K; zero-point correction of -0.03% determined by graphical extrapolation.
20*	116	Stejskal, M., et al.	1961	L	378-1257	HfO_2 - II	Similar to the above specimen; zero-point correction of -0.01% determined by graphical extrapolation.
21*	116	Stejskal, M., et al.	1961	L	377-1257	HfO_2 - III	Similar to the above specimen; zero-point correction of -0.01% determined by graphical extrapolation.
22*	116	Stejskal, M., et al.	1961	L	369-1254	HfO_2 - IV	Similar to the above specimen; zero-point correction of -0.03% determined by graphical extrapolation.
23	596 597	Stacy, D.W., Johnstone, J.K., and Wilder, D.R.	1971	X	293-1980		Monoclinic specimen from Wan Chang Corp. (Albany, Ore.) spectrographic grade hafnium oxychloride; analysis of sample showed 0.01 Cb, 0.005 Fe, 0.02 Ta, 0.006 Zr; sample converted to HfO_2 and sintered in Ar at 2173 K and ground to -325 mesh; monoclinic-tetragonal phase transformation near 2023 K; 2.7% contraction in unit-cell volume occurs during transformation; expansion measured along a-axis of monoclinic structure.
24	596 597	Stacy, D.W., et al.	1971	X	293-1980		Same as the above specimen except expansion measured along b-axis of monoclinic structure.
25	596 597	Stacy, D.W., et al.	1971	X	293-1980		Same as the above specimen except expansion measured along c-axis of monoclinic structure.
26	596 597	Stacy, D.W., et al.	1971	X	2034-2213		Same as the above specimen except expansion measured along a-axis of tetragonal structure.
27	596 597	Stacy, D.W., et al.	1971	X	2034-2213		Same as the above specimen except expansion measured along c-axis of tetragonal structure.
28	598	Patil, R.N. and Subbarao, E.C.	1969	X	303-1673		99.9 pure specimen; expansion measured along a-axis of monoclinic structure; lattice parameter reported at 303 K is 5.1093 Å; zero-point correction of 0.005% determined by graphical extrapolation.
29	598	Patil, R.N. and Subbarao, E.C.	1969	X	303-1673		Same as the above specimen; expansion measured along b-axis of monoclinic structure; lattice parameter reported at 303 K is 5.1686 Å; zero-point correction of 0.001% determined by graphical extrapolation.
30	598	Patil, R.N. and Subbarao, E.C.	1969	X	303-1673		Same as the above specimen; expansion measured along c-axis of monoclinic structure; lattice parameter reported at 303 K is 5.2839 Å; zero-point correction of 0.007% determined by graphical extrapolation.
31*	600	Filatov, S.K. and Frank-Kamenetskii, V.A.	1969	X	293-1473		99.1 HfO_2 and 0.8 ZrO_2; monoclinic structure; for 20-200 C parameters calculated from 041, 200, 022, $20\bar{2}$, $11\bar{1}$, and 111 peaks and for higher temperatures used 400, 130, 020, and 002 reflections; unit cell parameters along a-axis reported; 5.1174 Å reported at 293 K.
32	600	Filatov, S.K. and Frank-Kamenetskii, V.A.	1969	X	293-1473		Same as the above specimen; unit cell parameters along b-axis reported; 5.1731 Å reported at 293 K.
33	600	Filatov, S.K. and Frank-Kamenetskii, V.A.	1969	X	293-1473		Same as the above specimen; unit cell parameters along c-axis reported; 5.2887 Å reported at 293 K.

*Not shown in figure.

DATA TABLE 51. THERMAL LINEAR EXPANSION OF HAFNIUM DIOXIDE HfO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
296	0.000
1074	0.345
1178	0.488
1275	0.613
1377	0.667
1477	0.877
1675	1.027
1774	1.140
1874	1.163
1972	1.070
2069	0.403
2169	0.429
2255	0.514
CURVE 2	
2068	0.489
1868	0.801
1674	0.821
1477	0.759
1271	0.563
296	0.002*
CURVE 3	
296	0.002*
1119	0.353
1498	0.537
1837	0.774
2062	1.014
2118	0.807
2159	0.615
2186	0.536
2374	0.749
2649	1.092
CURVE 4	
2650	0.453
2233	-0.094
2088	0.375
1999	0.790
1242	0.252
304	0.005

T	$\Delta L/L_0$
CURVE 5	
301	0.00*
535	0.16
767	0.29
970	0.45
1176	0.66
1371	0.84
CURVE 6	
301	0.00*
535	0.00
767	0.04
970	0.06
1176	0.12
1371	0.23
CURVE 7	
301	0.01*
535	0.27
767	0.54
970	0.73
1176	1.05
1371	1.31
CURVE 8	
510	0.088
569	0.110
618	0.133
721	0.180
818	0.227
917	0.281
1016	0.338
1114	0.399
1213	0.462
1313	0.532
1339	0.553
1416	0.613
1490	0.677
1515	0.696
1591	0.752
CURVE 9	
523	0.133
1573	0.742

T	$\Delta L/L_0$
CURVE 10	
291	0.000*
366	0.076
477	0.126
588	0.199
699	0.254
810	0.318
922	0.393
1033	0.458
1144	0.525
1255	0.602
1366	0.681
1477	0.777
1588	0.863
1699	0.984
1810	1.123
1880	1.123
1922	1.093
2033	0.856
2088	0.827
2144	0.847
2255	0.986
2366	1.119
2477	1.249
2588	1.392
2699	1.561
2759	1.658
CURVE 11	
1147	0.329
1530	0.505
1854	0.731
2000	0.797*
2068	0.823
2087	0.597
2135	0.143
2162	0.151
2330	0.282
2506	0.498
CURVE 12	
2506	0.733
2169	0.311
2122	0.235
1958	0.933
1741	0.689
310	0.005*

T	$\Delta L/L_0$
CURVE 13	
1180	0.283
1473	0.416
1875	0.714
1945	0.749
2026	0.857*
2121	0.911
2142	0.389
2209	0.410
2342	0.586
2521	0.894
CURVE 14	
2521	0.639
2161	0.216
2125	0.401
2075	0.911
1830	0.810
305	0.003*
CURVE 15	
350	0.02
373	0.03
423	0.05
473	0.06
523	0.08
573	0.09
623	0.11
673	0.13
723	0.14
773	0.16
823	0.18
873	0.19
923	0.21
973	0.23
1023	0.24
1073	0.26
1123	0.27
1173	0.29
1223	0.31
1273	0.32
CURVE 16	
350	0.04
373	0.06

T	$\Delta L/L_0$
CURVE 16 (cont.)	
423	0.09
473	0.12
523	0.16*
573	0.19
623	0.22
673	0.25
723	0.29
773	0.32
823	0.35
873	0.38
923	0.42
973	0.45
1023	0.48
1073	0.51
1123	0.54
1173	0.58
1223	0.61
1273	0.64
1291	0.65
CURVE 17*	
350	0.05
373	0.06
423	0.08
473	0.13
523	0.16
573	0.20
623	0.23
673	0.26
723	0.30
773	0.33
823	0.36
873	0.39
923	0.43
973	0.47
1023	0.49
1073	0.52
1123	0.56
1173	0.59
1223	0.62
1273	0.66
1282	0.66

T	$\Delta L/L_0$
CURVE 18	
350	0.01
373	0.02
423	0.03
473	0.05
523	0.06
573	0.07*
623	0.09
673	0.10
723	0.11
773	0.12
823	0.13
873	0.13
923	0.14*
973	0.15
1023	0.16
1073	0.17*
1123	0.18
1173	0.20
1223	0.21*
1243	0.22
CURVE 19	
373	0.04*
423	0.06
473	0.09
523	0.11
573	0.14
623	0.16
673	0.19
723	0.21
773	0.24
823	0.26
873	0.29
923	0.31
973	0.34
1023	0.36
1073	0.39
1123	0.41
1173	0.44
1223	0.46*
1257	0.48
CURVE 20*	
378	0.04
423	0.06

* Not shown in figure.

DATA TABLE 51. THERMAL LINEAR EXPANSION OF HAFNIUM DIOXIDE HfO_2 (continued)

T	$\Delta L/L_0$
CURVE 20 (cont.)*	
473	0.09
523	0.12
573	0.14
623	0.17
673	0.19
723	0.22
773	0.24
823	0.27
873	0.29
923	0.32
973	0.34
1023	0.37
1073	0.39
1123	0.41
1173	0.44
1223	0.46
1257	0.48
CURVE 21*	
377	0.04
423	0.07
473	0.09
523	0.12
573	0.15
623	0.17
673	0.20
723	0.22
773	0.25
823	0.27
873	0.30
923	0.32
973	0.35
1023	0.37
1073	0.40
1123	0.43
1173	0.45
1223	0.47
1257	0.49
CURVE 22*	
369	0.04
423	0.07
473	0.09
523	0.12

T	$\Delta L/L_0$
CURVE 22 (cont.)*	
573	0.15
623	0.17
673	0.20
723	0.23
773	0.25
823	0.28
873	0.30
923	0.33
973	0.35
1023	0.38
1073	0.40
1123	0.43
1173	0.46
1223	0.48
1254	0.49
CURVE 23	
293	0.00*
1204	0.58
1319	0.74
1451	0.86
1496	1.05
1637	1.19
1745	1.27
1798	1.43
1846	1.31
1854	1.36
1859	1.22
1893	1.39
1921	1.48
1980	1.55
CURVE 24	
293	0.00*
1205	0.11
1321	0.16
1458	0.26
1500	0.31
1635	0.46
1749	0.29
1791	0.31
1843	0.28
1849	0.26
1856	0.24

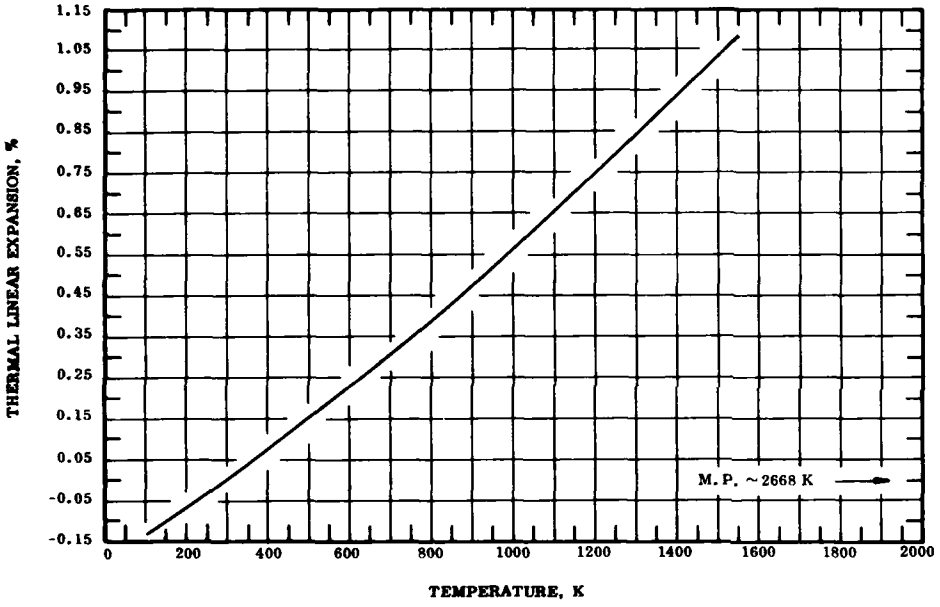
T	$\Delta L/L_0$
CURVE 24 (cont.)	
1894	0.29
1917	0.23
1980	0.20
CURVE 25	
293	0.00*
1207	0.92
1321	1.05
1453	1.24
1496	1.43
1635	1.81
1749	1.95
1796	1.99
1846	1.99
1850	2.08*
1856	2.06*
1894	2.16*
1917	2.30*
1980	2.37*
CURVE 26	
2034	0.729
2077	0.696
2097	0.807
2119	0.784
2128	0.818
2131	0.762
2183	0.889
2213	0.945
CURVE 27	
2034	0.201
2073	0.115
2097	0.231
2119	0.285
2133	0.194
2138	0.260
2183	0.450
2213	0.388
CURVE 28	
303	0.005

T	$\Delta L/L_0$
CURVE 28 (cont.)	
483	0.092
667	0.220
867	0.422
1073	0.558
1274	0.826
1456	0.975
1673	1.284
CURVE 29	
303	0.001*
483	0.013
667	0.066
867	0.035
1073	0.076
1274	0.267
1456	0.360
1673	0.410
CURVE 30	
303	0.007*
483	0.157
667	0.383
867	0.610
1073	0.818
1274	1.112
1456	1.483
1673	1.802
CURVE 31*	
293	0.000
473	0.070
673	0.199
873	0.408
1073	0.506
1273	0.760
1373	0.831
1473	0.971
CURVE 32	
293	0.000*
473	0.012
673	0.062*

T	$\Delta L/L_0$
CURVE 32 (cont.)	
873	0.099
1073	0.131
1273	0.155
1373	0.168
1473	0.178
CURVE 33	
293	0.000*
473	0.214
673	0.467
873	0.668
1073	0.959
1273	1.218
1373	1.344
1473	1.516

* Not shown in figure.

FIGURE AND TABLE NO. 52R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF HOLMIUM OXIDE Ho_2O_3



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
100	-0.131	6.5
150	-0.098	6.7
200	-0.065	6.8
250	-0.030	6.7
293	0.000	7.1
400	0.077	7.4
500	0.153	7.6
600	0.230	7.9
700	0.310	8.2
800	0.393	8.4
900	0.478	8.6
1000	0.566	8.9
1100	0.656	9.1
1200	0.747	9.3
1300	0.841	9.5
1400	0.937	9.7
1500	1.035	9.9
1550	1.085	10.0

REMARKS

The recommended values are based on the data for pure samples and are considered accurate to within ±3%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.196 + 6.240 \times 10^{-4} T + 1.494 \times 10^{-7} T^2 - 1.224 \times 10^{-11} T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±5%.

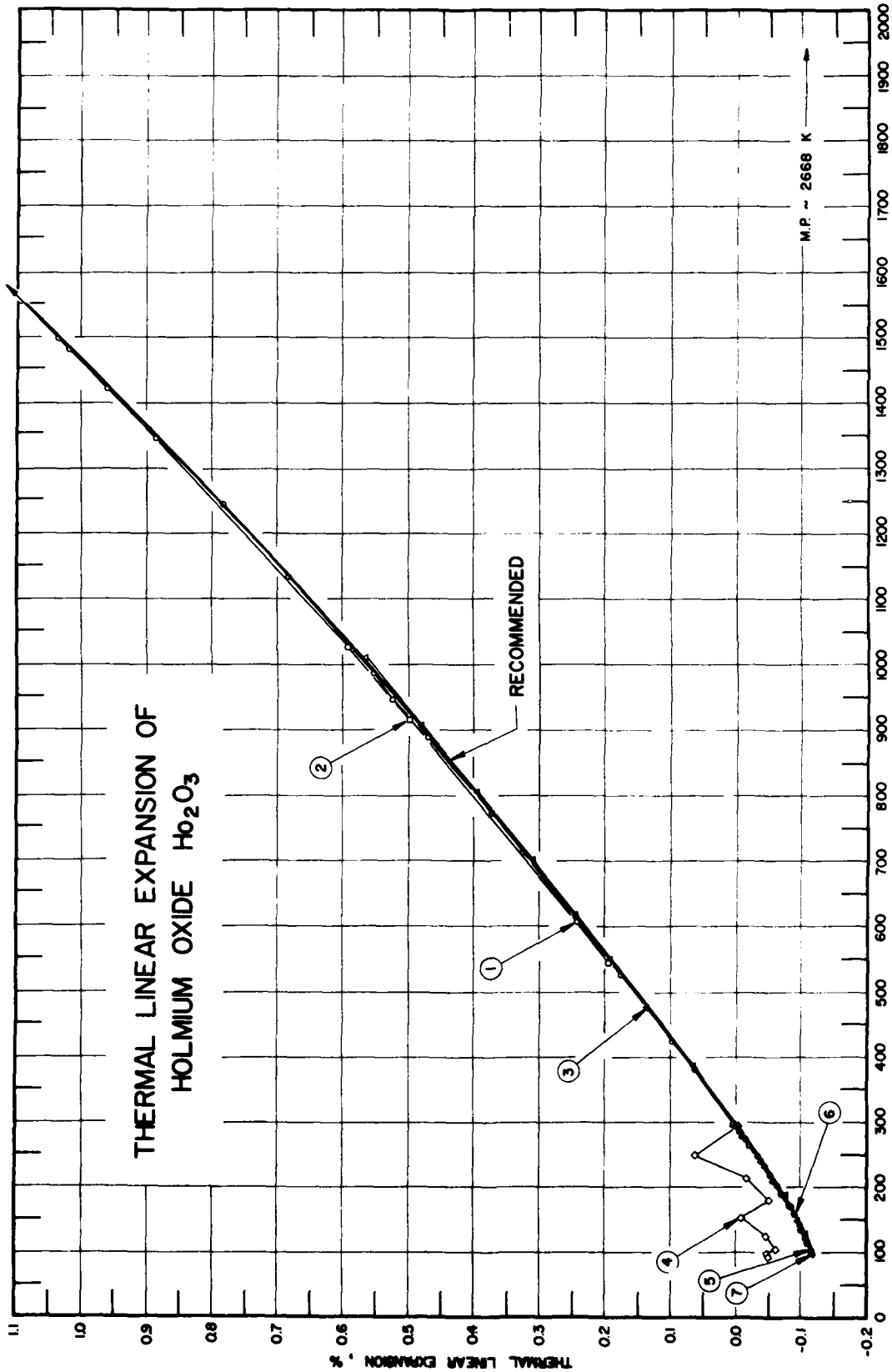

THERMAL LINEAR EXPANSION OF
HOLMIUM OXIDE Ho_2O_3
RECOMMENDED
M.P. ~ 2668 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
4
5
6
7

FIGURE 52

SPECIFICATION TABLE 52. THERMAL LINEAR EXPANSION OF HOLMIUM OXIDE Ho_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	68	Stecura, S. and Campbell, W.J.	1961	X	273-1568		99.9 pure; specimen obtained from Michigan Chemical Co.; sintered at 1573 K for 24 hr, packed in alumina holder, sintered at 1573 K for 24 hr, cooled to 473 K and stored in vacuum; unit cell parameter reported at 273.2 K is 10.6060 Å; zero-point correction of -0.015% determined by graphical interpolation.
2	68	Stecura, S. and Campbell, W.J.	1961	X	1346-547		Same as the above specimen; expansion measured with decreasing temperature; zero-point correction of -0.015% determined by graphical extrapolation.
3	96	Singh, H.P. and Dayal, B.	1969	X	296-1010		Specpure specimen, b.c. cubic structure; annealed at 808 K for 5 hr; filled into quartz capillary of 0.3 mm I.D.; lattice parameter reported at 296.2 K is 10.6078 Å; 10.6075 Å at 293.2 K determined by graphical extrapolation; data on the coefficient of thermal linear expansion also reported.
4	332	Mills, N.D.	1965	X	94-296		99.9+ pure; lattice parameter reported at 94 K is 10.59745 Å; 10.60283 Å at 293 K determined by graphical interpolation.
5	342	Gupta, M.L.	1968	X	108-290		99.9 pure powder form specimen; provided by Research Chemicals, Inc., Burbank, Calif.; annealed at 1373 K for 72 hr; lattice parameter reported at 108 K is 10.5938 Å; 10.6062 Å at 293 K determined by graphical extrapolation.
6	342	Gupta, M.L.	1968	X	300-116		Similar to the above specimen; expansion measured with decreasing temperature.
7	589	Gupta, M.L. and Singh, S.	1970	X	100-300		99.9 pure; specimen 9.5 mm diameter, 1 mm high; obtained in powder form from Research Chemicals, Inc., Phoenix, Ariz.; prepared using cement as binder; annealed at 1373 K for 72 hr; lattice parameter reported at 100 K is 10.5936 Å; 10.6062 Å at 293 K determined by graphical interpolation.

DATA TABLE 52. THERMAL LINEAR EXPANSION OF HOLMIUM OXIDE Ho_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
273	-0.015
299	0.004
381	0.064
425	0.098
528	0.177
606	0.243
711	0.327
773	0.374
889	0.473
948	0.526
985	0.555
1133	0.686
1242	0.787
1343	0.888
1420	0.964
1480	1.022
CURVE 1 (cont.)	
1498	1.040
1568	1.107
CURVE 2	
1346	0.888
1027	0.592
915	0.500
547	0.196
CURVE 3	
296	0.0028
388	0.0678
478	0.1385
550	0.1942
617	0.2479
701	0.3120
805	0.3978
908	0.4817
1010	0.5684
CURVE 4	
94	-0.05074
98	-0.04867
106	-0.06253
128	-0.04791
152	-0.00981
180	-0.05112
214	-0.01669
250	0.06385
296	-0.00443
CURVE 5	
108	-0.1169
126	-0.1074
146	-0.0989
175	-0.0810
205	-0.0622
235	-0.0414
265	-0.0197
290	-0.0018
CURVE 6	
300	0.0075*
280	-0.0084
250	-0.0320
220	-0.0518
190	-0.0707
CURVE 6 (cont.)	
160	-0.0905
136	-0.1008
116	-0.1103
CURVE 7	
100	-0.1188
110	-0.1150*
130	-0.1056
150	-0.0952
170	-0.0839
190	-0.0717
210	-0.0585
240	-0.0377
270	-0.0160*
300	0.0066*

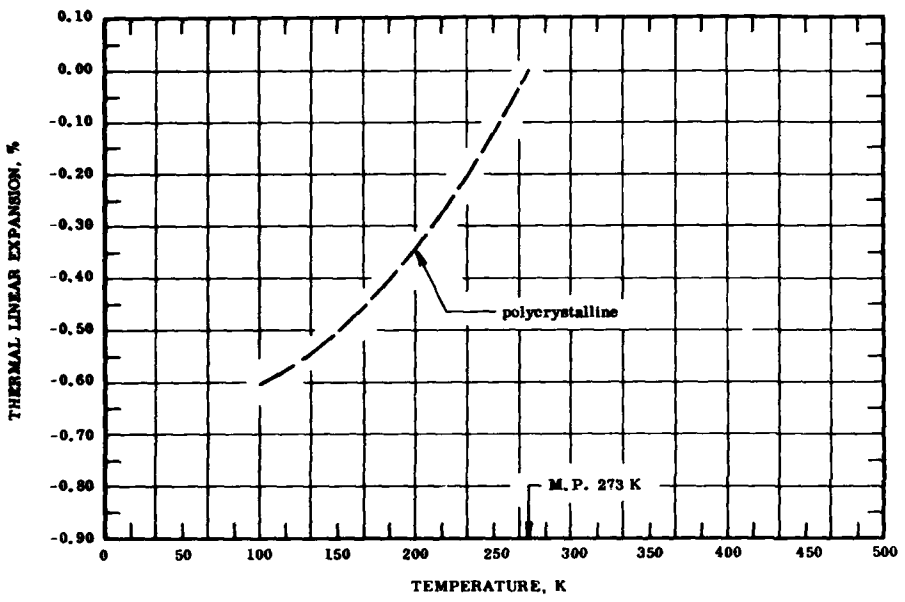
DATA TABLE 52. COEFFICIENT OF THERMAL LINEAR EXPANSION OF HOLMIUM OXIDE Ho_2O_3

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3	
296	7.40
388	7.53
478	7.66
550	7.77
617	7.87
701	8.00
805	8.17
908	8.34
1010	8.51

* Not shown in figure.

FIGURE AND TABLE NO. 53R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF HYDROGEN OXIDE H_2O



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$ ‡	α
100	-0.602	12
110	-0.590	15
120	-0.572	17
130	-0.550	20
140	-0.529	22
150	-0.502	25
160	-0.474	28
170	-0.446	30
180	-0.415	33
190	-0.382	36
200	-0.343	38
210	-0.305	41
220	-0.263	43
230	-0.218	45
240	-0.175	48
250	-0.125	50
260	-0.072	53
273	0.000	57

‡ Reference temperature 273 K at which $\Delta L/L_0 = 0$.

REMARKS

The provisional values for the polycrystalline sample of ordinary ice I at atmospheric pressure are considered accurate to within ± 7%. Ice I is one of at least nine polymorphic forms of ice. Ices II to VII are crystalline modifications formed at high pressures. Ice VIII is a low-temperature modification of ice VII. The inconsistency of the experimental data may be due to systematic differences between methods of measurement. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.661 - 3.239 \times 10^{-4}\, T + 8.228 \times 10^{-6}\, T^2 + 6.639 \times 10^{-9}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

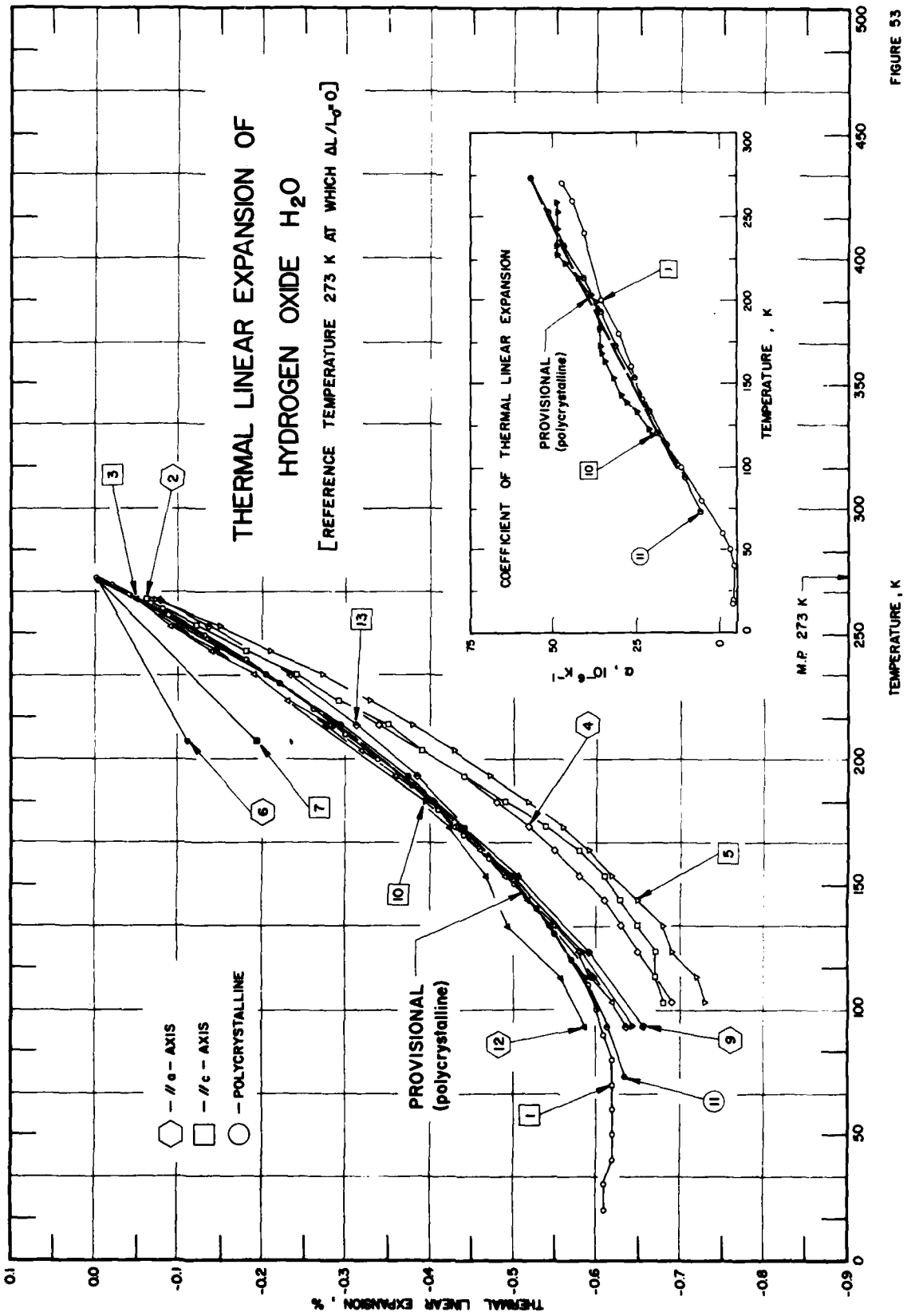

THERMAL LINEAR EXPANSION OF
HYDROGEN OXIDE H_2O
[REFERENCE TEMPERATURE 273 K AT WHICH $\Delta L/L_0=0$]
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
M.P. 273 K
PROVISIONAL
(polycrystalline)
// a - AXIS
// c - AXIS
POLYCRYSTALLINE
COEFFICIENT OF THERMAL LINEAR EXPANSION
α, 10^{-6} K^{-1}
TEMPERATURE, K

FIGURE 53

SPECIFICATION TABLE 53. THERMAL LINEAR EXPANSION OF HYDROGEN OXIDE H_2O

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	110	Dantl, G.	1962	I	20-273		Single crystal specimen; this curve is here reported using 273 K as reference temperature at which $\Delta L/L_0 = 0$; coefficient of thermal linear expansion also reported.
2	111	Handler, E. S.	1968	X	103-263		Cylindrical single crystal, hexagonal ice specimen; prepared by doubly distilling deionized water of desired isotopic composition, drown into 0.2 mm I.D., 15 mm long Lindemann glass capillary tube, frozen at 248 K for single crystal growth; lattice expansion measured along a-axis; 4.5206 Å reported at 263.2 K; reported error ±0.02%; this curve is here reported using 273 K as reference temperature at which $\Delta L/L_0 = 0$.
3	111	Handler, E. S.	1968	X	103-263		The above specimen; lattice expansion measured along c-axis; 7.3604 Å reported at 263.2 K; reported error ±0.01%; this curve is here reported using 273 K as reference temperature at which $\Delta L/L_0 = 0$.
4	111	Handler, E. S.	1968	X	103-263	H_2O^{18}	95.4 O^{18}, 0.58 O^{17}, <0.1 D; obtained from Dr. David Samuels of Weitzman Inst. (Rehovot, Israel); lattice expansion measured along a-axis; 4.5216 Å reported at 263.2 K; reported error ±0.02%; this curve is here reported using 273 K as reference temperature at which $\Delta L/L_0 = 0$.
5	111	Handler, E. S.	1968	X	103-263	H_2O^{18}	The above specimen; lattice expansion measured along c-axis; 7.3621 Å reported at 263.2 K; reported error ±0.01%; this curve is here reported using 273 K as reference temperature at which $\Delta L/L_0 = 0$.
6	363	Megaw, H. D.	1934	X	207, 273		Single crystal specimen; grown by inserting Lindemann glass tube into holder in contact with cooling mixture of acetone and solid carbon dioxide; plane (5$\bar{0}$50) used with CuKα radiation for measurement of a-axis of unit cell; 4.5135 Å reported at 273.2 K; this curve is here reported using 273.2 K as reference temperature at which $\Delta L/L_0 = 0$.
7	363	Megaw, H. D.	1934	X	207, 273		Similar to the above specimen; plane (0008) used with CoKα radiation for measurement of c-axis of unit cell; 7.3521 Å reported at 273.2 K; this curve is here reported using 273.2 K as reference temperature at which $\Delta L/L_0 = 0$.
8*	364	Butkovich, T. R.	1959	L	247-273	Sample No. 5	Expansion measured in aluminum V block of Statham displacement transducer, model G7-0.15; this curve is here reported using 273 K as reference temperature at which $\Delta L/L_0 = 0$; zero-point correction of 0.103%.
9	365	Kumai, M.	1967		93-273		Crystal specimen formed on surface which cooled to less than 183 K in pure nitrogen gas at atmospheric pressure; water vapor introduced to cold surface and crystal grew by sublimation; unit cell a-axis parameter expansion measured; 4.5227 Å reported at 273.2 K; this curve is here reported using 273.2 K as reference temperature at which $\Delta L/L_0 = 0$.
10	365	Kumai, M.	1967		93-273		The above specimen; unit cell c-axis parameter expansion measured; 7.3671 Å reported at 273.2 K; this curve is here reported using 273.2 K as reference temperature at which $\Delta L/L_0 = 0$; coefficient of thermal linear expansion also reported.
11	366	Powell, R. W.	1958	L	73-273		Rod specimen 0.25 in. dia, 4 in. long; cut from larger artificial single crystal; prepared by seeding and slow cooling of de-airated water and tested optically using plane-polarized light; this curve is here reported using 273 K as reference temperature at which $\Delta L/L_0 = 0$.

*Not shown in figure.

SPECIFICATION TABLE THERMAL LINEAR EXPANSION OF HYDROGEN OXIDE H_2O

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
12	1097	LaPlaca, S. and Post, B.	1960	X	93-263		Specimen prepared initially by spraying distilled water, in the form of fine mist, onto a cooled glass specimen holder; repeatedly warming the specimens showing high degrees of preferred orientation; expansion measured along a-axis of hexagonal structure ice under 1 atm; lattice parameter reported at 263 K is 4.5190 Å; 4.5213 Å at 273 K determined by graphical extrapolation; this curve is here reported using 273 K as reference temperature at which $\Delta L/L_0 = 0$.
13	1097	LaPlaca, S. and Post, B.	1960	X	93-263		The above specimen; expansion measured along c-axis of hexagonal structure ice under 1 atm; lattice parameter reported at 263 K is 7.3616 Å; 7.3671 Å at 273 K determined by graphical extrapolation; this curve is here reported using 273 K as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 53. THERMAL LINEAR EXPANSION OF HYDROGEN OXIDE H_2O

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
20	-0.61
30	-0.61
40	-0.62
50	-0.62
60	-0.62
70	-0.62
80	-0.62
80	-0.62
90	-0.61
100	-0.60
110	-0.59
120	-0.57
130	-0.55
140	-0.53
150	-0.50
160	-0.47
170	-0.44
180	-0.41
190	-0.38
200	-0.34
210	-0.30
220	-0.26
230	-0.22
240	-0.18
250	-0.13
260	-0.08
270	-0.02
273	0.00
CURVE 2‡	
103	-0.68
113	-0.67
123	-0.67
133	-0.65
143	-0.63
153	-0.61
163	-0.58
173	-0.54
183	-0.49
193	-0.44
203	-0.39
213	-0.35
223	-0.29
233	-0.24
243	-0.18
253	-0.12
263	-0.06

T	$\Delta L/L_0$
CURVE 3‡	
103	-0.62
113	-0.59
123	-0.58
133	-0.55
143	-0.52
153	-0.49
163	-0.46
173	-0.43
183	-0.40
193	-0.36
203	-0.32
213	-0.28
223	-0.23
233	-0.19
243	-0.14
253	-0.09
263	-0.05
CURVE 4‡	
103	-0.69
113	-0.67
123	-0.65
133	-0.63
143	-0.61
153	-0.58
163	-0.55
173	-0.52
183	-0.48
193	-0.44
203	-0.39
213	-0.34
223	-0.29
233	-0.24
243	-0.18
253	-0.12
263	-0.06
CURVE 5‡	
103	-0.73
113	-0.72
123	-0.69
133	-0.68
143	-0.65
153	-0.62
163	-0.59
173	-0.56

T	$\Delta L/L_0$
CURVE 5 (cont.)‡	
183	-0.52
193	-0.47
203	-0.43
213	-0.38
223	-0.33
233	-0.27
243	-0.21
253	-0.15
263	-0.07
CURVE 6‡	
207	-0.1107
273	0.0000
CURVE 7‡	
207	-0.1917
273	0.0000
CURVE 8*,‡	
241	-0.103
241	-0.102
242	-0.101
243	-0.097
245	-0.091
247	-0.085
249	-0.078
255	-0.060
256	-0.057
257	-0.053
260	-0.044
262	-0.036
266	-0.024
269	-0.012
271	-0.007
273	0.000
CURVE 9‡	
93	-0.6566
123	-0.5903
153	-0.5063
183	-0.4046
213	-0.2830
243	-0.1415
273	0.0000

T	$\Delta L/L_0$
CURVE 10‡	
92	-0.6447
123	-0.5850
153	-0.5008
183	-0.3963
213	-0.2850
243	-0.1438
273	0.0000
CURVE 11‡,‡	
73	-0.634
93	-0.615
113	-0.587
133	-0.548
153	-0.500
173	-0.441
193	-0.372
213	-0.294
233	-0.205
253	-0.107
273	0.000
CURVE 12	
93	-0.586
113	-0.557
133	-0.493
153	-0.469
173	-0.425
193	-0.356*
213	-0.276
233	-0.188*
253	-0.097
263	-0.051*
CURVE 13	
93	-0.638
113	-0.594
133	-0.548*
153	-0.498*
173	-0.444*
193	-0.384
213	-0.314
233	-0.232
253	-0.137
263	-0.075

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.
‡ This curve is here reported using 273 K as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 53. COEFFICIENT OF THERMAL LINEAR EXPANSION OF HYDROGEN OXIDE H_2O

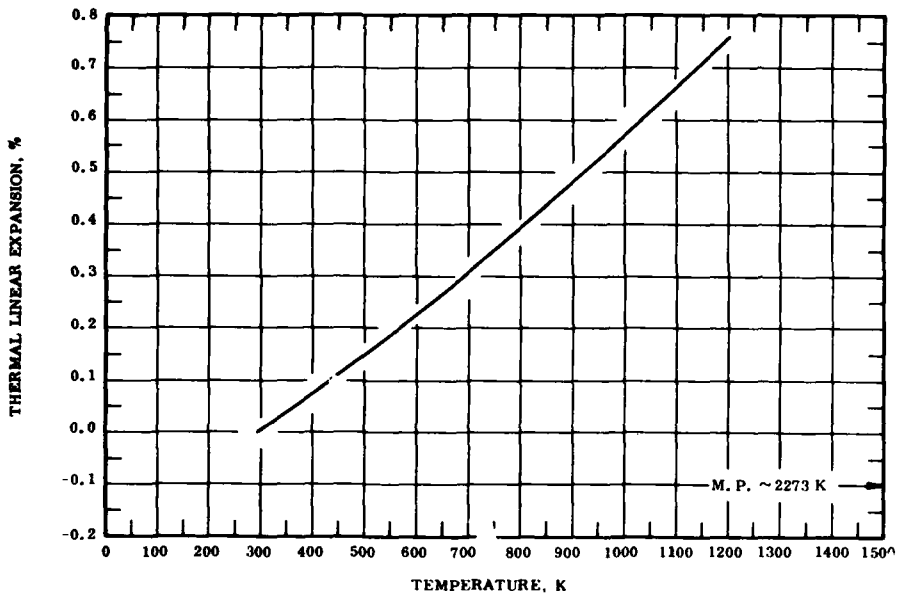
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1	
18	-3.8
20	-3.8
40	-4.3
50	-3.0
60	-0.9
80	5.3
100	12.8
120	18.5
140	23.1
160	27.4
180	31.8
200	36.0
240	40.3
260	44.5
270	47.2
CURVE 10	
119	20.0
123	21.9
133	26.3
137	28.5
143	29.6
153	32.1
163	34.6
167	35.7
173	36.0
183	36.7
193	37.1
199	37.1
203	38.8
213	42.6
223	46.8
227	48.3
233	48.2
243	48.2
253	48.3
259	46.3
CURVE 11‡	
73	6.8
93	11.7
113	16.8
133	21.7
CURVE 11 (cont.)‡	
153	26.7
173	31.9
193	36.8
213	41.8
233	46.6
253	51.5
273	56.2

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 54R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF INDIUM OXIDE In_2O_3



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	6.9
400	0.076	7.3
500	0.151	7.6
600	0.229	8.0
700	0.310	8.3
800	0.395	8.6
900	0.482	8.9
1000	0.572	9.1
1100	0.665	9.4
1200	0.760	9.7

REMARKS

The recommended values are based on the data for pure samples and are considered accurate to within ±5%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.186 + 5.791 \times 10^{-4}\, T + 2.024 \times 10^{-7}\, T^2 - 2.299 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±7%.

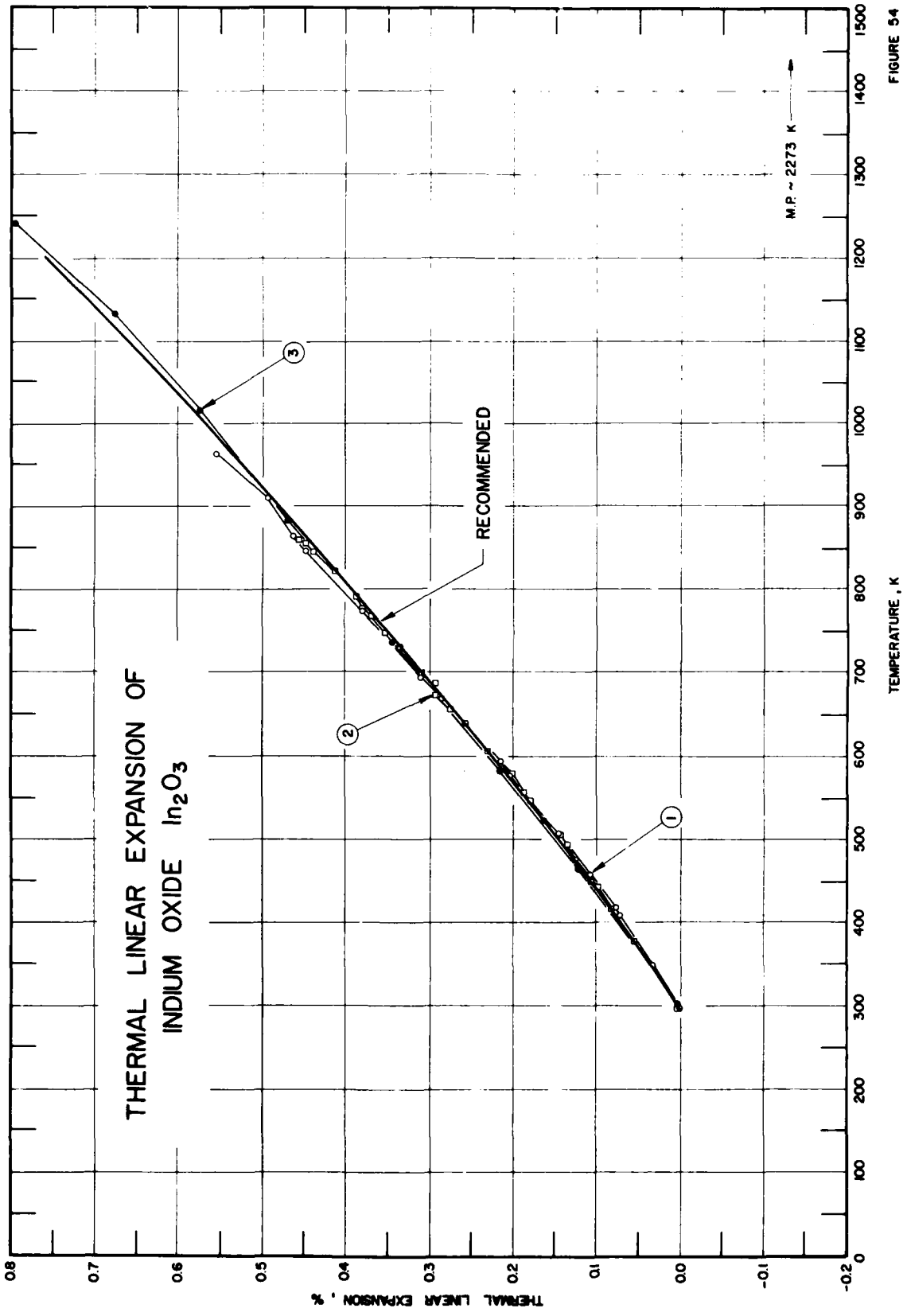

THERMAL LINEAR EXPANSION OF
INDIUM OXIDE In_2O_3
RECOMMENDED
M.P. ~ 2273 K
1
2
3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 54

SPECIFICATION TABLE 54. THERMAL LINEAR EXPANSION OF INDIUM OXIDE In_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	112	Weiker, R.L. and Ley, R.P.	1963	L	273-961		Sintered microcrystalline powder specimen; prepared by pressing powder into pellet form and heating in air atmosphere at 1773 K for 24 hr; 55% of theoretical density; zero-point correction of -0.0100% determined by graphical interpolation.
2	112	Weiker, R.L. and Ley, R.P.	1963	L	273-860		Single crystal specimen; zero-point correction of -0.0120% determined by graphical interpolation.
3	606	Kundra, K.D. and Ali, S.Z.	1969	X	303-1241		Powder prepared by vapor phase oxidation; specimen "spec pure" from Johnson Matthey and Co.; 200 B.S. mesh, estimated error ±0.0005 Å, temperature ±5 C; cell constant reported at 303 K is 10.1194 Å; 10.1189 Å at 293 K determined by graphical extrapolation.

DATA TABLE 54. THERMAL LINEAR EXPANSION OF INDIUM OXIDE In_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 2 (cont.)		CURVE 3 (cont.)	
296	0.0012	296	0.0023	687	0.2927	583	0.2184
349	0.0338	373	0.0556	699	0.3096	736	0.3469
407	0.0720	415	0.0821	730	0.3362	881	0.4704
416	0.0769	440	0.0996	748	0.3533	1016	0.5761
457	0.1090	448	0.1084	769	0.3694	1131	0.6779
507	0.1470	474	0.1259	775	0.3796	1241	0.7965
522	0.1630	491	0.1356	790	0.3882		
577	0.2049	505	0.1444	821	0.4143		
593	0.2159	522	0.1616*	846	0.4407		
669	0.2850	547	0.1787	856	0.4492		
693	0.3109	558	0.1875	860	0.4576		
774	0.3798	579	0.2025				
847	0.4492	605	0.2314	CURVE 3			
865	0.4648	638	0.2581				
910	0.4939	655	0.2749	303	0.0049		
961	0.5548	672	0.2920	463	0.1216		

*Not shown in figure.

SPECIFICATION TABLE 55. THERMAL LINEAR EXPANSION OF IRIDIUM DIOXIDE IrO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	117	Rao, K.V.K. and Iyengar, L.	1969	X	301-975		Powdered specimen; tetragonal rutile type structure; obtained from Dr. W. D. Ryden of Univ. of California; prepared by filling in thin-walled quartz capillary; expansion measured along a-axis; lattice parameter reported at 301.2 K is 4.4985 Å; 4.4984 Å at 293.2 K determined by graphical extrapolation.
2*	117	Rao, K.V.K. and Iyengar, L.	1969	X	301-975		The above specimen; expansion measured along c-axis; lattice parameter at 301.2 K is 3.1548 Å; 3.1547 Å at 293.2 K determined by graphical extrapolation.

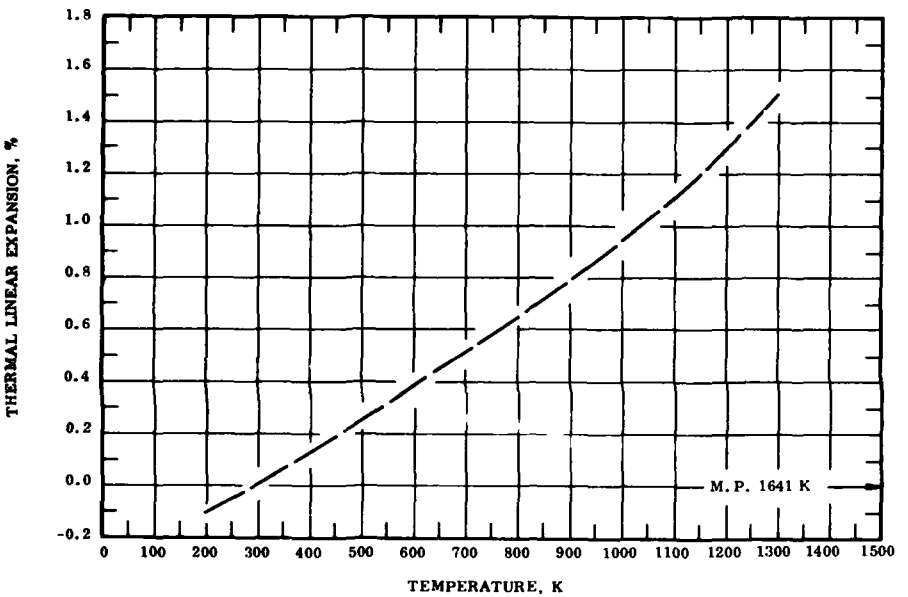
DATA TABLE 55. THERMAL LINEAR EXPANSION OF IRIDIUM DIOXIDE IrO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2 (cont.)*	
301	0.0022	734	0.1331
438	0.0555	836	0.1680
540	0.1133	928	0.1965
634	0.1667	975	0.2282
734	0.2289		
836	0.2934		
928	0.3556		
975	0.3934		
CURVE 2*			
301	0.0031		
438	0.0316		
540	0.0602		
634	0.0982		

* No figure given.

FIGURE AND TABLE NO. 56R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF IRON MONOXIDE FeO



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
200	-0.110	11.9
250	-0.050	11.9
293	0.000	12.0
400	0.139	12.0
500	0.255	12.2
600	0.382	12.3
700	0.508	12.8
800	0.640	13.6
900	0.781	14.8
1000	0.936	16.2
1100	1.100	18.0
1200	1.296	20.1
1300	1.512	22.6

REMARKS

The provisional values are considered accurate to within ±7% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.409 + 1.602 \times 10^{-5} T - 7.913 \times 10^{-9} T^2 + 5.348 \times 10^{-10} T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

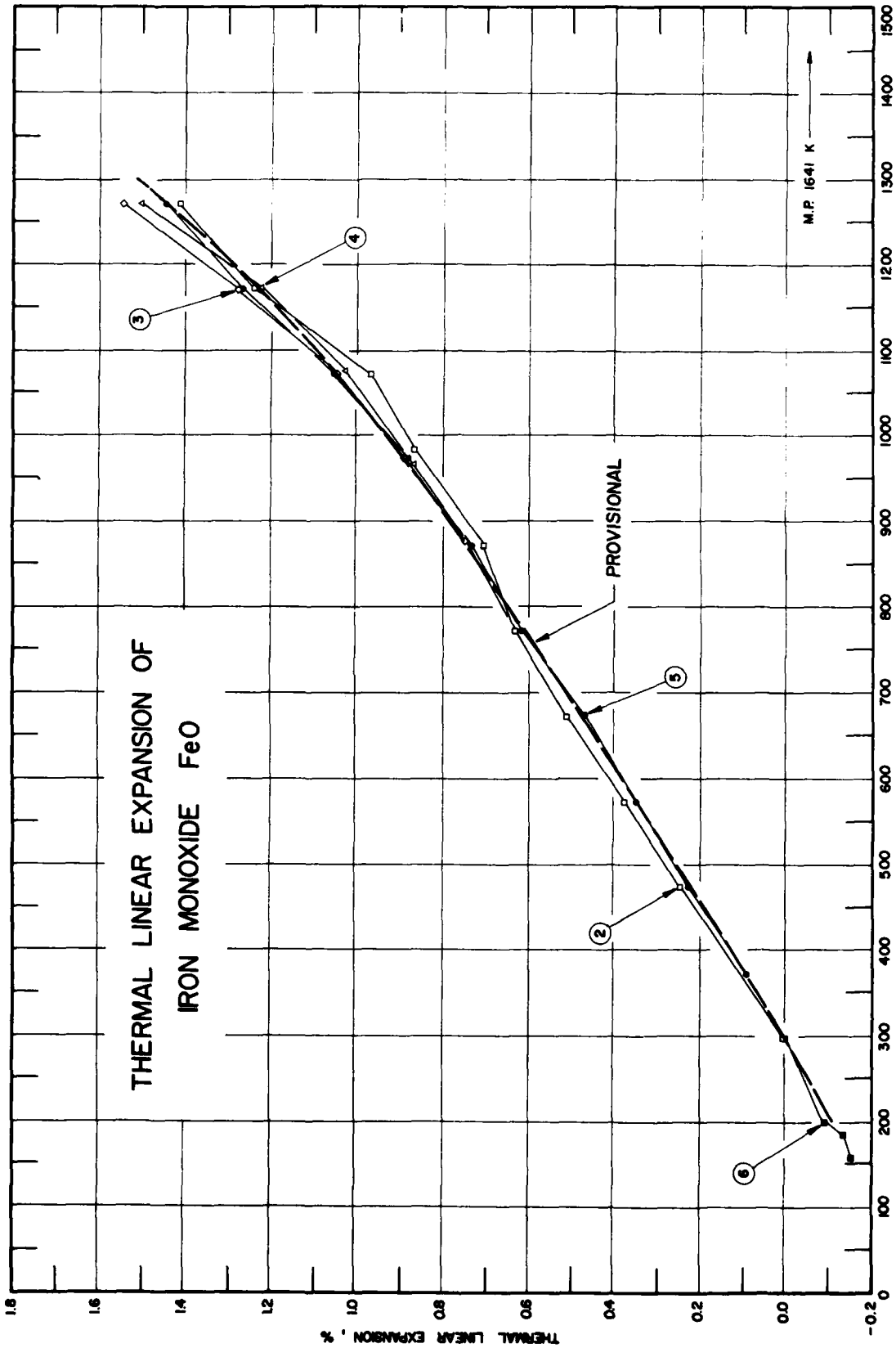

THERMAL LINEAR EXPANSION OF
IRON MONOXIDE FeO
PROVISIONAL
M.P. 1641 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
2
3
4
5
6

FIGURE 56

SPECIFICATION TABLE 56. THERMAL LINEAR EXPANSION OF IRON MONOXIDE FeO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	118	Gorton, A.T., Bitsianes, G., and Joseph, T.L.	1965	X	873-1273	$Fe_{0.924}O$ Wüstite	76.31 Fe; synthetic specimen; prepared by reacting stoichiometric amounts of Baker's reagent-grade hematite with electrolytic iron at 1173 K under vacuum; lattice parameter reported at 873 K is 4.3315 Å; data reported using first given temperature as the reference temperature.
2	119	Carter, R.E.	1959	L	298-1273	Wüstite	Bar specimen 0.25 x 0.25 x 1.25 in.; prepared by decomposing 99.7 pure Fe_2O_3 in platinum boat at 1273 K for 15 hr in H_2O:H ratio 0.88 atmosphere and quenched at same atmosphere, ground and mixed resultant with 2% Carbowax 4000, pressed into bar, sintered and quenched under same condition as before; 66% of theoretical density.
3	119	Carter, R.E.	1959	L	1273-879	Wüstite	The above specimen; expansion measured with decreasing temperature on first test.
4	119	Carter, R.E.	1959	L	298-1273	Wüstite	The above specimen; expansion measured with increasing temperature on second test.
5	119	Carter, R.E.	1959	L	1273-373	Wüstite	The above specimen; expansion measured with decreasing temperature on second test.
6	120	Ellefson, B.S. and Taylor, N.W.	1934	X	160-299		Powder specimen; obtained from Dr. Charles G. Maier of the Bureau of Mines Pacific Experiment Station, Berkeley, Calif.; lattice constant reported at 160 K is 4.283 Å; 4.2896 Å at 293 K determined by graphical interpolation.

DATA TABLE 56. THERMAL LINEAR EXPANSION OF IRON MONOXIDE FeO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*,†	
873	0.000
973	0.143
1073	0.275
1173	0.415
1273	0.547
CURVE 2	
298	0.003*
373	0.099*
473	0.249
573	0.378
673	0.510
773	0.633
873	0.705

T	$\Delta L/L_0$
CURVE 2 (cont.)	
981	0.867
1073	0.963
1173	1.241
1273	1.415
CURVE 3	
1273	1.546
1173	1.277
1073	1.051
973	0.890
879	0.747

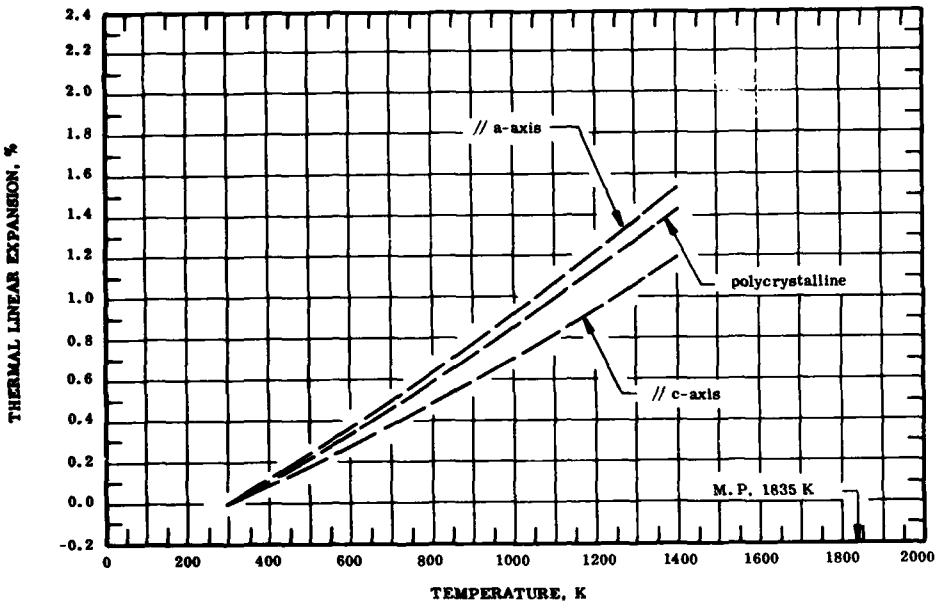
T	$\Delta L/L_0$
CURVE 4	
298	0.008
967	0.870
1077	1.031
1173	1.223
1273	1.502
CURVE 5	
1273	1.444
1173	1.273
1073	1.052
973	0.882
873	0.735
773	0.620

T	$\Delta L/L_0$
CURVE 5 (cont.)	
673	0.466
573	0.348
473	0.228
373	0.096
CURVE 6	
160	-0.154
186	-0.130
200	-0.084
299	0.009

*Not shown in figure.

†This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

FIGURE AND TABLE NO. 57R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF IRON OXIDE Fe_2O_3



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	9.9
400	0.121	0.096	0.110	10.7
500	0.241	0.189	0.221	11.4
600	0.369	0.286	0.338	12.0
700	0.502	0.387	0.462	12.6
800	0.640	0.491	0.590	13.1
900	0.782	0.599	0.722	13.5
1000	0.929	0.711	0.859	13.8
1100	1.079	0.827	1.000	14.1
1200	1.230	0.948	1.140	14.3
1300	1.384	1.073	1.284	14.4
1400	1.539	1.202	1.430	14.5

REMARKS

The provisional values for the axial thermal expansion of the sample of hexagonal structure are based on the data for the crystal samples. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ±7% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -2.814 + 8.224 \times 10^{-4}\ T + 5.049 \times 10^{-7}\ T^2 - 1.170 \times 10^{-10}\ T^3$

// c-axis: $\Delta L/L_0 = -2.443 + 7.891 \times 10^{-4}\ T + 1.468 \times 10^{-7}\ T^2 + 1.968 \times 10^{-11}\ T^3$

polycrystalline: $\Delta L/L_0 = -2.537 + 7.300 \times 10^{-4}\ T + 4.964 \times 10^{-7}\ T^2 - 1.140 \times 10^{-10}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

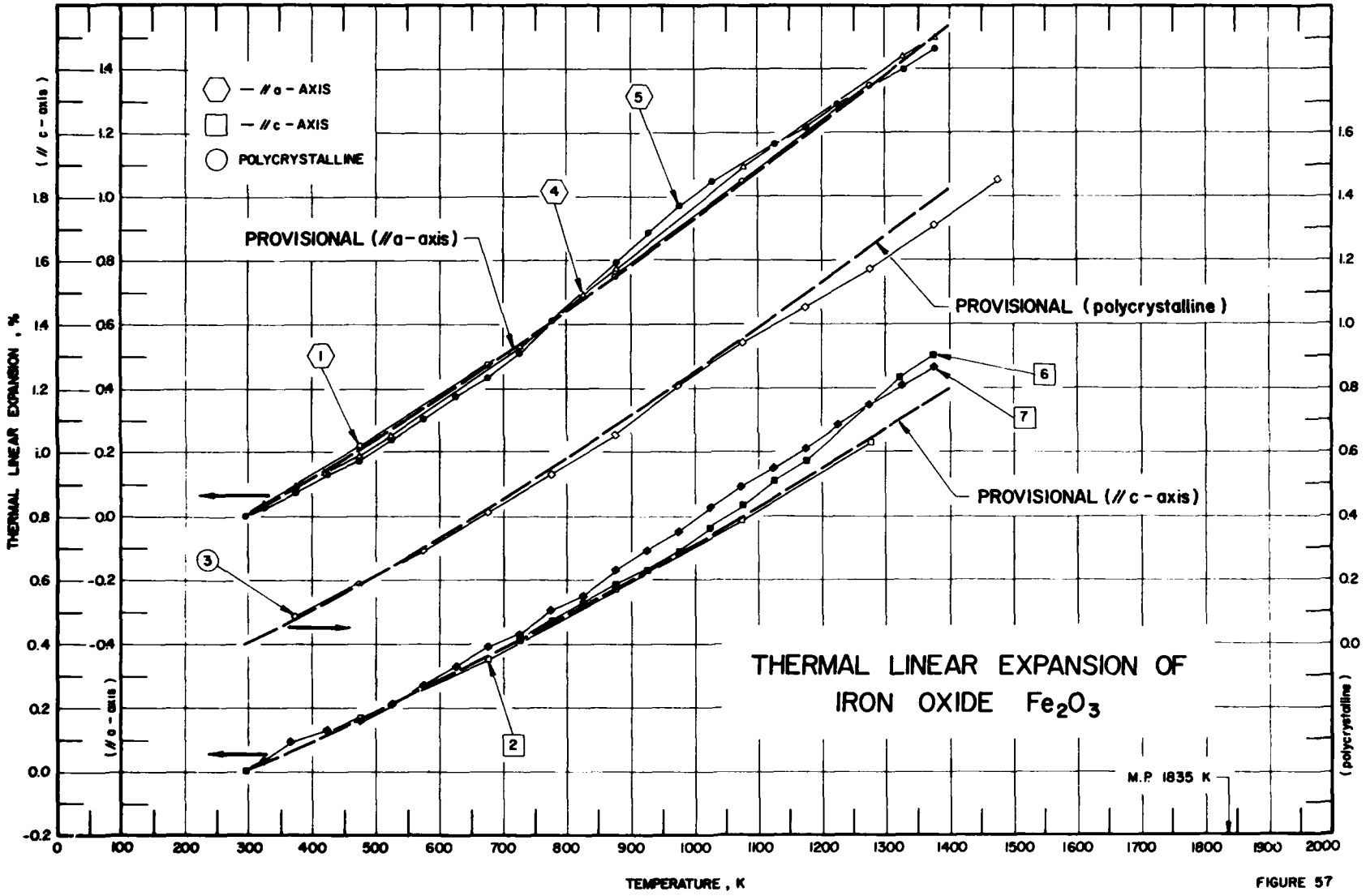

— // a - AXIS
— // c - AXIS
POLYCRYSTALLINE
PROVISIONAL (// a - axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// c - axis)
1
2
3
4
5
6
7
THERMAL LINEAR EXPANSION OF
IRON OXIDE Fe_2O_3
M.P 1835 K
THERMAL LINEAR EXPANSION , %
(// c - axis)
(// a - axis)
(polycrystalline)
TEMPERATURE , K
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
-0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8
-0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6

FIGURE 57

SPECIFICATION TABLE 57. THERMAL LINEAR EXPANSION OF IRON OXIDE Fe_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	118	Gorton, A.T., Bitsianes, G., and Joseph, T.L.	1965	X	298-1273	Hexagonal	National Hematite Crystal; specimen obtained from Island of Elba, Italy; expansion measured along a-axis; lattice parameter reported at 298.2 K is 5.0314 Å; 5.0311 Å at 293.2 K determined by graphical extrapolation; coefficient of thermal linear expansion also reported.
2	118	Gorton, A.T., et al.	1965	X	298-1273	Hexagonal	The above specimen; expansion measured along c-axis; lattice parameter reported at 298.2 K is 13.756 Å; 13.755 Å at 293.2 K determined by graphical extrapolation; coefficient of thermal linear expansion also reported.
3	122	Rigby, G.R. and Green, A.T.	1943	L	373-1473		Thermal expansion measurements were made, both on specimens of 97.28 pure Fe_2O_3 from Jewellers' rouge and 96.42 pure Fe_2O_3 obtained by oxidation of mill scale; averaged data reported; zero-point correction of 0.082% determined by graphical extrapolation.
4	123	Saito, T.	1967	X	324-1376	α-Fe_2O_3 hexagonal	Natural crystal specimen; hexagonal lattice parameters increased uniformly from room temperature to about 573 K, and they also increased uniformly above about 973 K, however, in the temperature range from about 573-973 K, the two axes showed different expansion behavior; expansion measured along a-axis.
5	123	Saito, T.	1967	X	1376-293	α-Fe_2O_3 hexagonal	The above specimen; expansion measured with decreasing temperature.
6	123	Saito, T.	1967	X	672-1372	α-Fe_2O_3 hexagonal	Similar to the above specimen; expansion measured along c-axis.
7	123	Saito, T.	1967	X	1373-293	α-Fe_2O_3 hexagonal	The above specimen; expansion measured with decreasing temperature.
8*	123	Saito, T.	1967	X	375-1374	α-Fe_2O_3 rhombohedral	Natural crystal specimen; expansion measured along a-axis.
9*	123	Saito, T.	1967	X	1374-293	α-Fe_2O_3 rhombohedral	The above specimen; expansion measured with decreasing temperature.

* Not shown in figure.

DATA TABLE 57. THERMAL LINEAR EXPANSION OF IRON OXIDE Fe_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.0059
473	0.2206
673	0.4750
873	0.7473
1073	1.0454
1273	1.3356
CURVE 2	
298	0.0072
473	0.1672
673	0.3562
873	0.5670
1073	0.7851
1273	1.0250
CURVE 3	
373	0.082*
473	0.184*
573	0.298*
673	0.410
773	0.531
873	0.656
973	0.805
1073	0.940
CURVE 3 (cont.)	
1173	1.058
1273	1.177
1373	1.317
1473	1.455
CURVE 4	
324	0.038
374	0.091
420	0.132
473	0.183
522	0.250
725	0.525
827	0.696
879	0.776
1075	1.098
1328	1.441
1376	1.500
CURVE 5	
1376	1.461
1328	1.409
1274	1.352*
1221	1.294
1175	1.220
CURVE 5 (cont.)	
1127	1.161
1075	1.094*
1029	1.044
975	0.976
928	0.890
879	0.796
827	0.690*
774	0.608
726	0.509
673	0.429
625	0.376
573	0.300
522	0.240
474	0.167
421	0.129
374	0.071
324	0.026
293	0.000*
CURVE 6	
672	0.357*
725	0.408
775	0.470
825	0.522
873	0.585
CURVE 6 (cont.)	
925	0.626
973	0.684
1023	0.760
1072	0.834
1121	0.908
1172	0.975
1320	1.232
1372	1.301
CURVE 7	
1373	1.261
1321	1.204
1272	1.143
1221	1.085
1172	1.012
1121	0.948
1072	0.891
1023	0.822
973	0.751
925	0.695
873	0.626
825	0.550
775	0.501
725	0.429
672	0.394
CURVE 7 (cont.)	
624	0.332
574	0.273
523	0.214
475	0.160
422	0.134*
369	0.090
324	0.027
293	0.000*
CURVE 8*	
375	0.079*
474	0.151
626	0.286
674	0.337
773	0.422
825	0.460
873	0.508
924	0.515
974	0.567
1024	0.648
1077	0.730
1124	0.797
1174	0.876
1374	1.204
CURVE 9*	
1374	1.175
1324	1.134
1274	1.057
1227	0.993
1174	0.940
1125	0.861
1077	0.797
1024	0.722
975	0.664
925	0.612
873	0.566
825	0.499
773	0.467
726	0.416
678	0.360
626	0.317
574	0.278
524	0.234*
474	0.198
423	0.137*
375	0.095*
326	0.043*
293	0.000*

DATA TABLE 57. COEFFICIENT OF THERMAL LINEAR EXPANSION OF IRON OXIDE Fe_2O_3

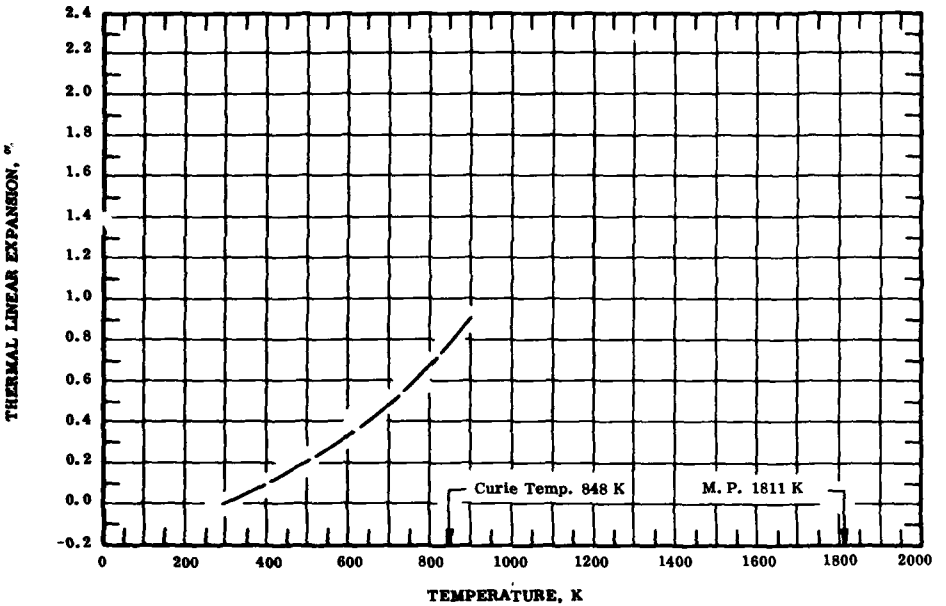
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1*,‡	
298	11.75
373	11.97
473	12.40
573	12.83
673	13.25
773	13.68
873	14.10
973	14.52
CURVE 1 (cont.)*,‡	
1073	14.94
1173	15.36
1273	15.78
CURVE 2*,‡	
298	9.38
373	9.49
CURVE 2 (cont.)*,‡	
473	9.65
573	9.80
673	9.95
773	10.09
873	10.25
973	10.41
1073	10.55
1173	10.70
1273	10.85

*Not shown in figure.

‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 58R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF TRIIRON TETRAOXIDE Fe_3O_4



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	8
400	0.097	10
500	0.206	12
600	0.340	14
700	0.495	17
800	0.683	21
900	0.910	24

REMARKS

The provisional values are based on the data for crystal sample and are considered accurate to within ±7%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.214 + 6.929 \times 10^{-4}\ T - 1.107 \times 10^{-6}\ T^2 + 8.078 \times 10^{-10}\ T^3$$

The tabulated values for the coefficient of thermal expansion are derived from the experimental data (curve 2) and are considered accurate to about ±7%.

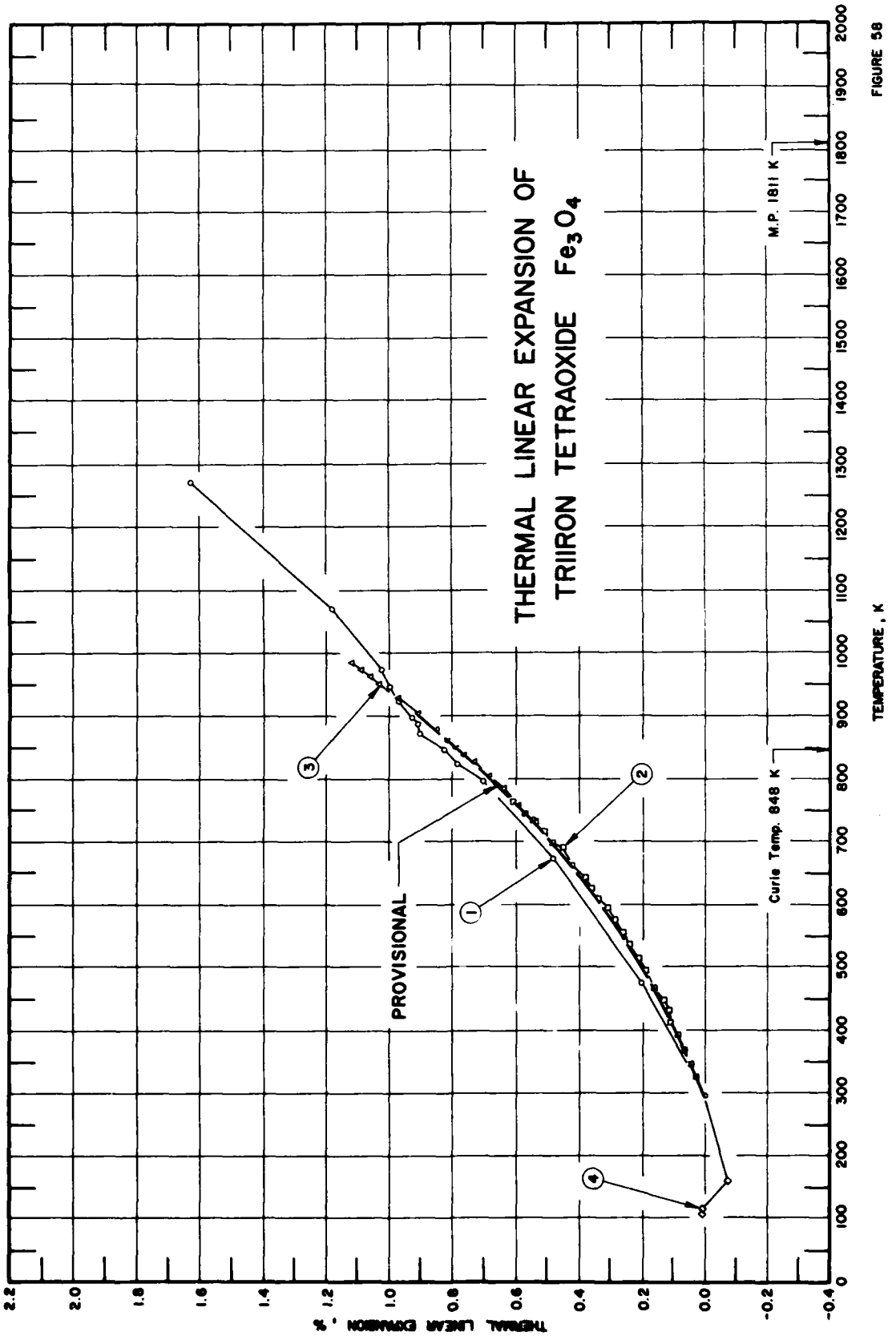

THERMAL LINEAR EXPANSION OF
TRIIRON TETRAOXIDE Fe_3O_4
PROVISIONAL
Curie Temp. 848 K
M.P. 1811 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
4

FIGURE 58

SPECIFICATION TABLE 58. THERMAL LINEAR EXPANSION OF TRIIRON TETRAOXIDE Fe_3O_4

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	118	Gorton, A.T., Bitsianes, G., and Joseph, T.L.	1965	X	298-1273		Natural magnetite crystal; octahedral structure specimen; obtained from N.Y.; magnetic transformation temperature range 798 to 973 K; lattice parameter reported at 298.2 K is 8.3963 Å; 8.3962 Å at 293.2 K determined by graphical extrapolation; coefficient of thermal linear expansion also reported.
2	121	Sharma, S.S.	1950	I	326-764	I Run	Crystal specimen of iron-black color; dodecahedral faces fully developed; Curie-point at about 848 K, below which it is ferromagnetic and above the Curie-point it exhibits paramagnetism; initial length at 273 K is 0.4435 cm; density 5.180 g cm^{-3}; zero-point correction of -0.006% determined by graphical extrapolation; coefficient of thermal linear expansion also reported.
3	121	Sharma, S.S.	1950	I	735-985	II Run	The above specimen; expansion measured on second test including the Curie-point (848 K); zero-point correction is 0.5410%; coefficient of thermal linear expansion also reported.
4	120	Ellefson, B.S. and Taylor, N.W.	1934	X	104-299		Powder specimen; obtained from Dr. C. G. Maier of Bureau of Mines Pacific Experiment Station, Berkeley, California; lattice constant reported at 104 K is 8.363 Å; 8.362 Å at 293 K determined by graphical interpolation.
5*	331	Okamura, T.	1932	L	89-173		Natural crystal specimen; obtained from Kamaishi, Japan; allotropic transformation in the range of temperature 107 to 115 K; heating rate 1/7 C per min; data from smoothed curve.

* Not shown in figure.

DATA TABLE 58. THERMAL LINEAR EXPANSION OF TRIIRON TETRAOXIDE Fe_3O_4

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.0012
473	0.2060
673	0.4907
798	0.7075
823	0.7896
848	0.8289
873	0.9076
888	0.9159
898	0.9338
923	0.9778
948	1.0028
973	1.0231
1073	1.1839
1273	1.6365

T	$\Delta L/L_0$
CURVE 2	
326.1	0.014184
348.6	0.034088
370.3	0.053773
391.4	0.073297
411.6	0.092681
431.0	0.11195
450.0	0.13113
468.6	0.15024
491.6	0.17560
514.1	0.20087
535.0	0.22605
555.0	0.25116
574.2	0.27623
592.6	0.30126
610.1	0.32623
626.7	0.35118
643.0	0.37611
662.0	0.40722
680.8	0.43832
699.2	0.46938
716.6	0.50042
733.0	0.53145

T	$\Delta L/L_0$
CURVE 2 (cont.)	
748.8	0.56244
764.4	0.59343
CURVE 3*,†	
734.8	0.5410
759.9	0.5906
784.0	0.6402
806.7	0.6897
828.6	0.7392
839.0	0.7639
850.5	0.7887
861.8	0.8134
878.1	0.8505
904.0	0.9123
928.7	0.9741
951.8	1.0359
963.1	1.0668
974.3	1.0977
985.1	1.1285

T	$\Delta L/L_0$
CURVE 4	
104	0.0119
114	0.0119
160	-0.0597
299	0.0119
CURVE 5*	
89	0.0142
93	0.0142
98	0.0143
103	0.0143
108	0.0144
110	0.0144
113	0.0120
117	0.00933
118	0.00889
123	0.00829
128	0.00771
133	0.00711
138	0.00658
143	0.00602
148	0.00553

T	$\Delta L/L_0$
CURVE 5 (cont.)*	
153	0.00497
158	0.00448
163	0.00391
168	0.00341
173	0.00282

DATA TABLE 58. COEFFICIENT OF THERMAL LINEAR EXPANSION OF TRIIRON TETRAOXIDE Fe_3O_4

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1*	
298	10.41
373	11.38
473	12.68
573	13.97
673	15.26
773	16.54
973	19.05
1073	20.35
1173	21.61
1273	22.85

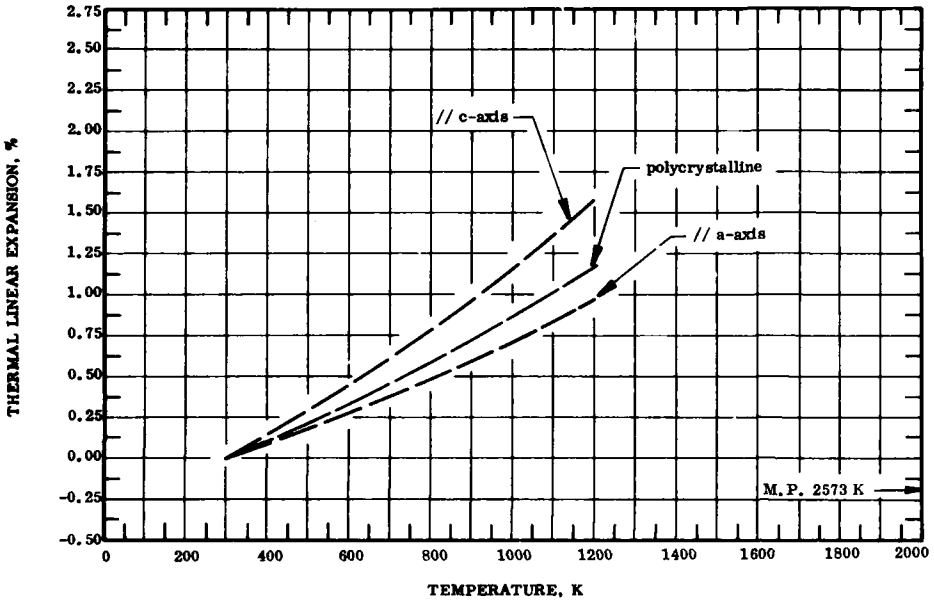
T	α
CURVE 2*	
314.5	8.698
359.4	9.074
401.5	9.594
440.5	10.09
480.1	11.03
524.6	12.05
564.6	13.05
601.4	14.29
634.9	15.30
671.4	16.51
707.9	17.84
740.9	19.62
756.6	19.87

T	α
CURVE 3*	
747.4	19.75
772.0	20.56
795.4	21.82
817.7	22.60
833.8	23.76
844.7	21.55
856.2	21.90
870.0	22.76
891.1	23.86
916.4	25.01
940.2	26.74
957.5	27.34
968.7	27.57
979.7	28.59

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

FIGURE AND TABLE NO. 59R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF LANTHANUM OXIDE La_2O_3



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	10.8
400	0.155	0.092	0.114	11.0
500	0.300	0.183	0.225	11.3
600	0.460	0.277	0.340	11.7
700	0.630	0.380	0.463	12.3
800	0.780	0.480	0.582	12.9
900	0.977	0.594	0.720	13.6
1000	1.170	0.714	0.860	14.4
1100	1.370	0.842	1.010	15.3
1200	1.577	0.979	1.170	16.3

REMARKS

The provisional values for the axial thermal expansion are based on the data for pure samples. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ± 7% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -0.388 + 1.261 \times 10^{-3}\ T + 1.902 \times 10^{-7}\ T^2 + 1.032 \times 10^{-10}\ T^3$

// a-axis: $\Delta L/L_0 = -0.239 + 7.991 \times 10^{-4}\ T + 2.663 \times 10^{-8}\ T^2 + 1.280 \times 10^{-10}\ T^3$

polycrystalline: $\Delta L/L_0 = -0.312 + 1.070 \times 10^{-3}\ T - 5.990 \times 10^{-8}\ T^2 + 1.628 \times 10^{-10}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 10%.

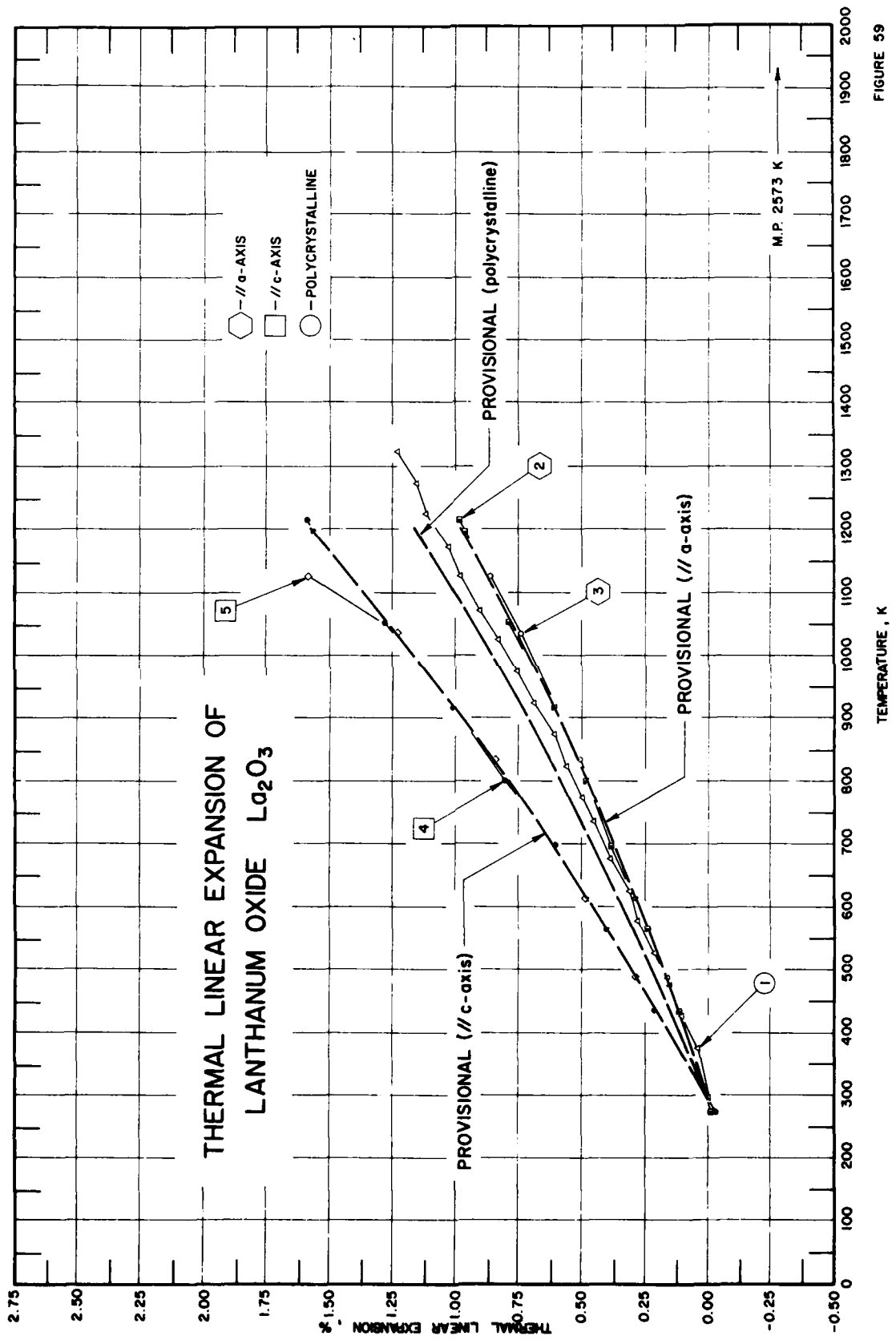

THERMAL LINEAR EXPANSION OF
LANTHANUM OXIDE La_2O_3
// a-AXIS
// c-AXIS
POLYCRYSTALLINE
PROVISIONAL (polycrystalline)
PROVISIONAL (// a-axis)
PROVISIONAL (// c-axis)
M.P. 2573 K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1
2
3
4
5

FIGURE 59

SPECIFICATION TABLE 59. THERMAL LINEAR EXPANSION OF LANTHANUM OXIDE La_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	125	Mistler, R.E., Ploetz, G.L., and Smith, J.A.	1963	L	298-1323	La_2O_3 - 529	99.997 pure; specimen obtained from Lindsey Chemical Div. of American Potash and Chemical Corp., West Chicago, Illinois; dry-pressed at pressure of 20 000 psi in double acting steel die into pellet 0.5 in. diameter, 2 in. long; pellet sintered at 1723 K for 1 hr in oxidizing atmosphere, furnace cooled to 473 K and then cooled to room temperature in vacuum desiccator; zero-point correction of 0.003% determined by graphical extrapolation.
2	68	Stecura, S. and Campbell, W.J.	1961	X	273-1214		99.9 pure; specimen obtained from Lindsey Chemical Co.; sintered at 1273 K for 24 hr, cooled to 773 K, packed into alumina holder, sintered again at 1273 K for 24 hr, cooled to 1023 K; stored in vacuum; expansion measured along a-axis; data show a marked change near 1238 K which may be the inversion point for hexagonal type oxide; unit cell parameter reported at 273.2 K is 3.9365 Å; zero-point correction of -0.016% determined by graphical interpolation.
3	68	Stecura, S. and Campbell, W.J.	1961	X	1125-487		The above specimen; expansion measured along a-axis with decreasing temperature; zero-point correction of -0.016% determined by graphical extrapolation.
4	68	Stecura, S. and Campbell, W.J.	1961	X	273-1214		The above specimen; expansion measured along c-axis; unit cell parameter reported at 273.2 K is 6.1277 Å; zero-point correction of -0.025% determined by graphical interpolation.
5	68	Stecura, S. and Campbell, W.J.	1961	X	1125-487		The above specimen; expansion measured along c-axis with decreasing temperature; zero-point correction of -0.025% determined by graphical extrapolation.

DATA TABLE 59. THERMAL LINEAR EXPANSION OF LANTHANUM OXIDE La_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
298	0.003
373	0.047
423	0.102
473	0.151
523	0.208
573	0.261
623	0.321
673	0.380
733	0.454
773	0.500
823	0.564
873	0.629
923	0.690
973	0.759
1023	0.831
1073	0.903

CURVE 1 (cont.)

T	$\Delta L/L_0$
1124	0.976
1173	1.037
1224	1.113
1273	1.174
1323	1.238

CURVE 2

T	$\Delta L/L_0$
273	-0.016
296	0.002*
435	0.119
561	0.243
696	0.378
800	0.479
919	0.617
1052	0.777

CURVE 2 (cont.)

T	$\Delta L/L_0$
1197	0.957
1214	0.972

CURVE 3

T	$\Delta L/L_0$
1125	0.868
1031	0.749
831	0.512
611	0.294
487	0.167

CURVE 4

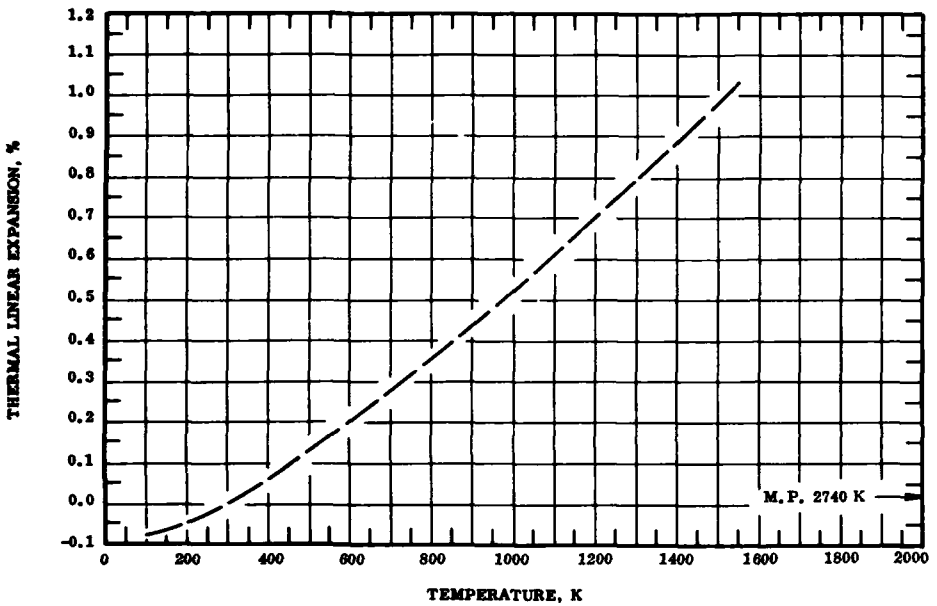
T	$\Delta L/L_0$
273	-0.025
296	0.004*
435	0.208
561	0.414
696	0.623
800	0.802
919	1.011
1052	1.264
1197	1.565
1214	1.592

CURVE 5

T	$\Delta L/L_0$
1125	1.592
1031	1.220
831	0.848
611	0.494
487	0.297

*Not shown in figure.

FIGURE AND TABLE NO. 60R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF LUTETIUM OXIDE Lu_2O_3



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
100	-0.078	4.0
150	-0.070	4.4
200	-0.048	4.8
250	-0.023	5.2
293	0.000	5.5
400	0.062	6.2
500	0.127	6.8
600	0.200	7.3
700	0.275	7.8
800	0.355	8.2
900	0.440	8.5
1000	0.525	8.8
1100	0.612	9.0
1200	0.705	9.1
1300	0.794	9.2
1400	0.896	9.3
1500	0.980	9.6
1550	1.030	9.7

REMARKS

The provisional values are based on the data for pure samples and are considered accurate to within ±7%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.127 + 3.110 \times 10^{-4}\, T + 4.522 \times 10^{-7}\, T^2 - 1.125 \times 10^{-10}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

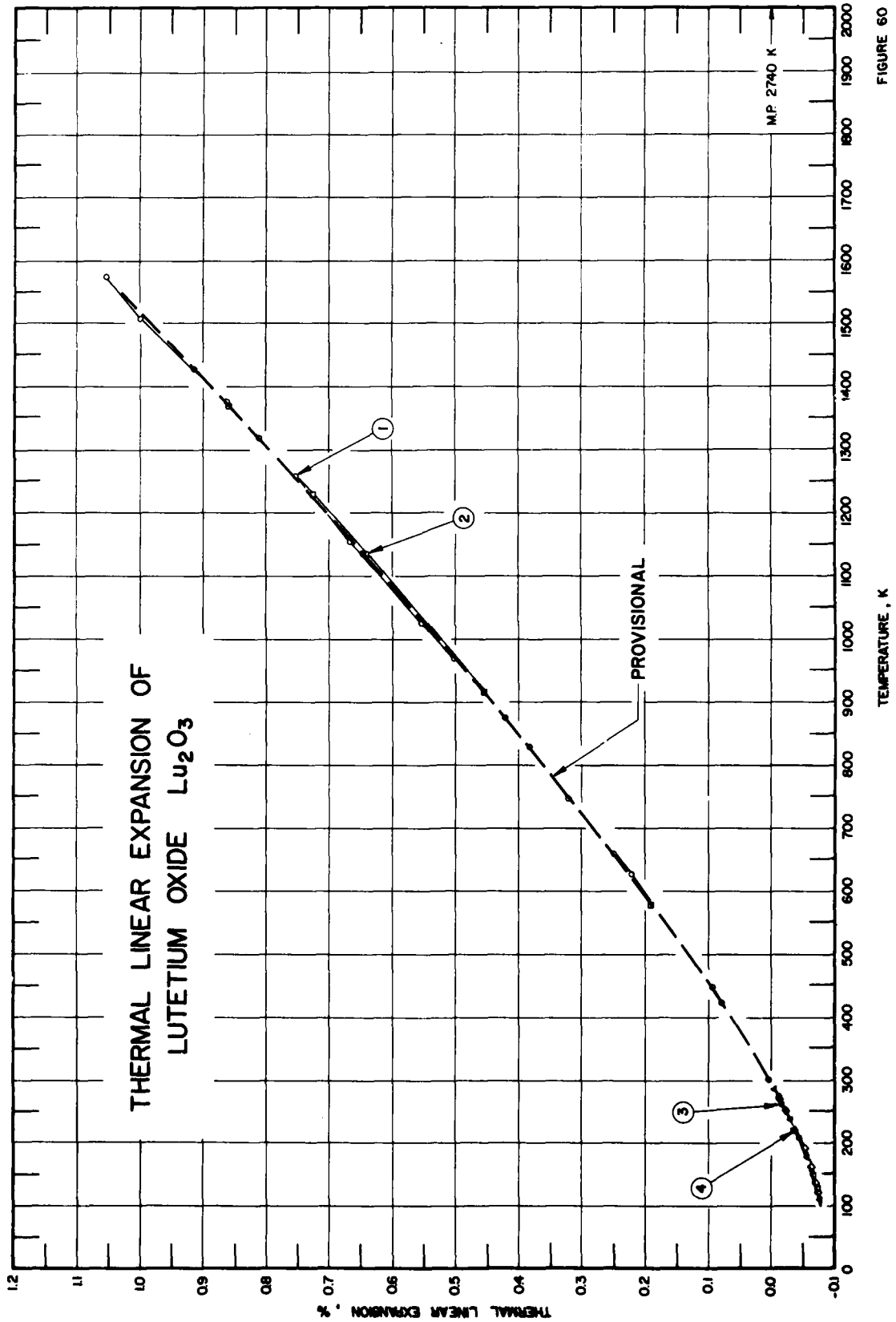

THERMAL LINEAR EXPANSION OF
LUTETIUM OXIDE Lu_2O_3
PROVISIONAL
M.P. 2740 K
1
2
3
4
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 60

SPECIFICATION TABLE 60. THERMAL LINEAR EXPANSION OF LUTETIUM OXIDE Lu_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	68	Stecura, S. and Campbell, W.J.	1961	X	273-1573		99.9 pure; specimen obtained from Lindsay Chemical Co.; sintered at 1473 K for 24 hr, packed into alumina holder, sintered again at 1523 K for 12 hr, cooled to 573 K; stored in vacuum; unit cell parameter reported at 273.2 K is 10.3847 Å; zero-point correction of -0.012% determined by graphical interpolation.
2	68	Stecura, S. and Campbell, W.J.	1961	X	1368-578		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.012% determined by graphical extrapolation.
3	342	Gupta, M.L.	1968	X	110-285		99.9 pure powder from specimen; provided by Research Chemicals, Inc., Burbank, Calif.; annealed at 1373 K for 72 hr; lattice parameter reported at 110 K is 10.3810 Å; 10.3892 Å at 293 K determined by graphical extrapolation.
4	342	Gupta, M.L.	1968	X	300-120		Similar to the above specimen; expansion measured with decreasing temperature.
5*	589	Gupta, M.L. and Singh, S.	1970	X	100-300		99.9 pure specimen; 9.5 mm diameter, 1 mm high; obtained in powder form from Research Chemicals, Inc., Phoenix, Ariz.; prepared using cement as binder; annealed at 1373 K for 72 hr; lattice parameter expansion measured; 10.3808 Å reported at 100 K; 10.3892 Å at 293 K determined by graphical interpolation.

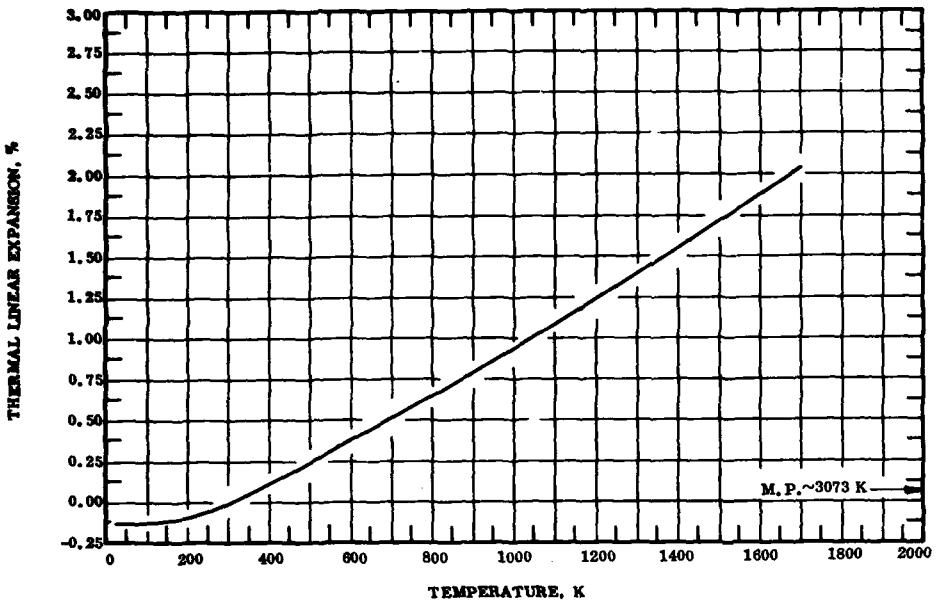
DATA TABLE 60. THERMAL LINEAR EXPANSION OF LUTETIUM OXIDE Lu_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 3 (cont.)		CURVE 5*	
273	-0.012	1508	1.000	205	-0.0452	100	-0.0809
300	0.004	1573	1.056	235	-0.0308	110	-0.0789
421	0.080			260	-0.0163	130	-0.0751
448	0.095	CURVE 2		285	-0.0038	150	-0.0693
625	0.223					170	-0.0616
658	0.250	1368	0.861	CURVE 4		190	-0.0529
745	0.323	1227	0.727			210	-0.0433
828	0.385	1133	0.644	300	0.0067*	240	-0.0279
872	0.422	913	0.458	270	-0.0125	270	-0.0116
968	0.503	578	0.192	250	-0.0231	300	0.0058
1023	0.554			220	-0.0365		
1133	0.647	CURVE 3		190	-0.0529		
1153	0.669			160	-0.0654		
1257	0.754	110	-0.0789	136	-0.0741		
1318	0.813	128.5	-0.0760	120	-0.0760		
1373	0.866	148	-0.0693				
1425	0.916	175	-0.0587				

* Not shown in figure.

FIGURE AND TABLE NO. 61R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF MAGNESIUM OXIDE MgO



RECOMMENDED VALUES

[Temperature, T, K, Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
25	-0.135	0.02
50	-0.134	0.2
75	-0.130	1.0
100	-0.130	2.2
150	-0.110	5.0
200	-0.080	7.6
250	-0.030	9.3
293	0.000	10.5
400	0.128	11.8
500	0.255	12.7
600	0.380	13.3
700	0.518	14.0
800	0.656	14.5
900	0.800	14.8
1000	0.944	15.0
1100	1.092	15.2
1200	1.244	15.4
1300	1.400	15.7
1400	1.558	16.0
1500	1.710	16.2
1600	1.880	16.5
1700	2.050	16.7

REMARKS

The recommended values are based on the data for pure samples and are considered accurate to within ±3%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.326 + 1.940 \times 10^{-3}\, T + 2.581 \times 10^{-7}\, T^2 - 2.834 \times 10^{-11}\, T^3 \qquad (293\text{-}1700\ K)$$

The tabulated values for the coefficient of thermal expansion are derived from the experimental data (curves 1, 26, 81 and 89) and are considered accurate to about ±5%.

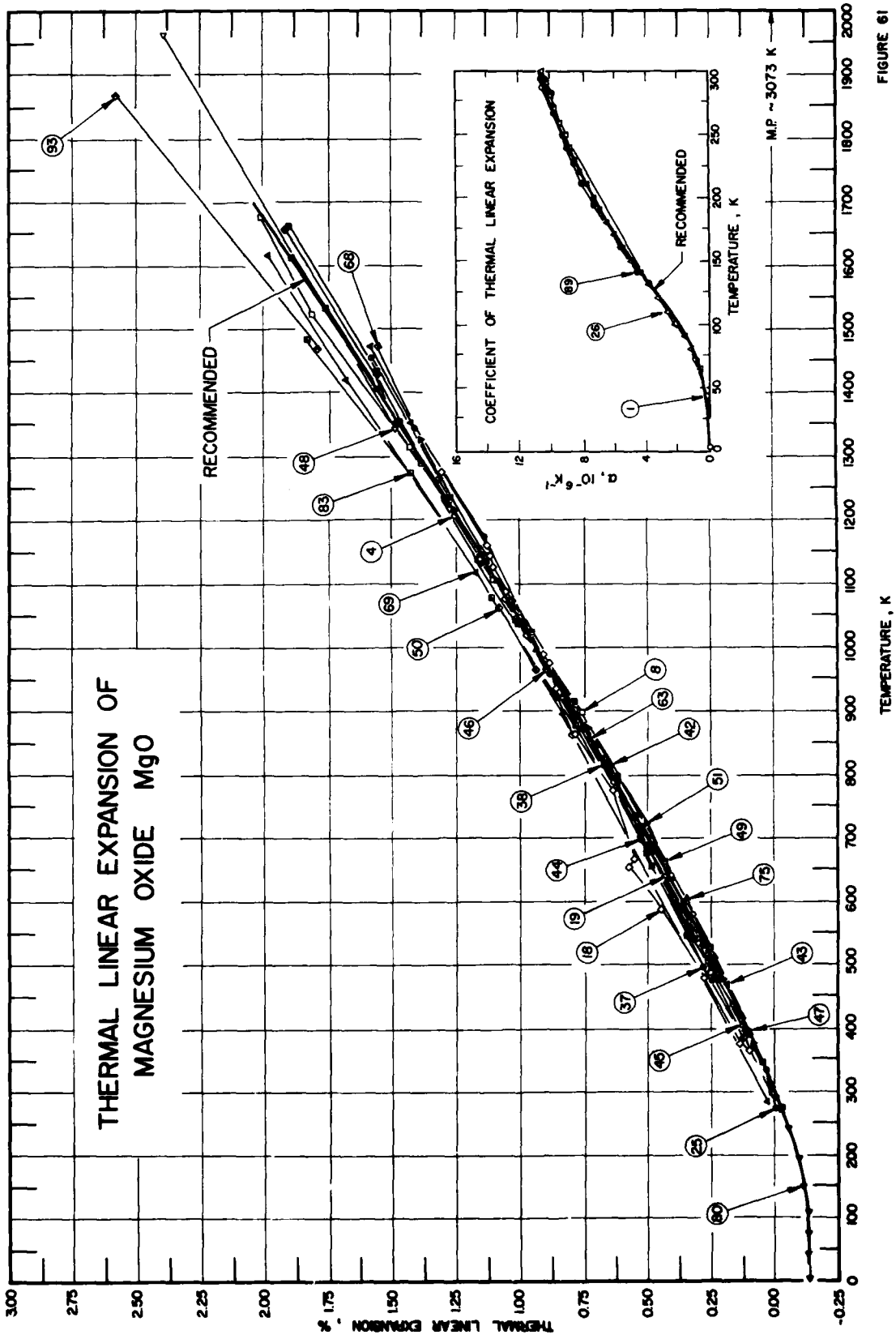

THERMAL LINEAR EXPANSION OF
MAGNESIUM OXIDE MgO
RECOMMENDED
M.P. ~ 3073 K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
α, 10⁻⁶ K⁻¹
TEMPERATURE, K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K

FIGURE 61

SPECIFICATION TABLE 61. THERMAL LINEAR EXPANSION OF MAGNESIUM OXIDE MgO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	51	White, G.K. and Anderson, O.L.	1966	E	4-293		Specimen 1 cm dia, 4 cm long; silver plated; expansion measured in absolute cell down to liquid-helium temp.
2*	1	Whittemore, O.J. Jr. and Ault, N.N.	1956	T	298-1773		Coarse fused grain specimen; 0.5 x 0.5 x 7 in.; ends sawed at rake and to point.
3*	1	Whittemore, O.J. Jr. and Ault, N.N.	1956	T	302-1773		Similar to the above specimen; except fine fused grain; heating rate 200 C per hr; zero-point correction of 0.002% determined by graphical extrapolation.
4	144	Merryman, R.G. and Kempter, C.P.	1965	X	298-1205		Powder specimen; expansion measured with gold internal standard; the lattice parameter at 25 C 4.21282 Å.
5*	7	Kirchner, H.P., Gruver, R.M. and Walker, R.E.	1966	X	299-1280		Commercially available specimen; crushed; zero-point correction of 0.006% determined by graphical extrapolation.
6*	69	Finlay, G.R.	1952		293,1073		Specimen density 3.58 g cm^{-3}.
7*	9	Sterry, W.M.	1960		344-883		Commercially available specimen; data from smoothed curve.
8	10	Mauer, F.A. and Bolz, L.H.	1955	X	273-1677		99.6 pure; powder specimen; obtained from Norton Co; zero-point correction of -0.025% determined by graphical interpolation.
9*	59	Bobrowsky, A.R.	1949		300,866		No details given.
10*	145	Gangler, J.J.	1950	I	366-781		Hot pressed specimen; data from smoothed curve.
11*	11	Austin, J.B.	1931	I	293-1273		Crystal specimen; obtained from Norton Co.
12*	44	Shakhtin, D.M., Levintovich, E.V., Pivovar, T.L. and Eliseeva, G.G.	1968	T	573-2063		99.5 pure; rectangular block specimen, 6-8 x 10-12 x 75-80 mm; two symmetrical open channels of 4 x 6 x 30 mm running along each end; expansion measured in argon atm.
13*	63	Pears, C.D.	1963	L	294-2983	Run E-13	0.3 Fe, 0.3 Si, 0.2 Ca, 0.1 Al impurities before exposure; obtained from Zirconium Corp. of America; initial length 2.953 in., final length 2.887 in.; density 3.30 g cm^{-3} at 25 C before exposure; expansion measured in helium atm; reported error 5%.
14*	13	Gardner, W.J., McClelland, J.D. and Richardson, J.H.	1963	L	473-1273	Baker's AR grade	Translucent specimen; 2 in. dia, 0.25 in. thick; hot pressed with pressure initially applied at 900 C, increased gradually to final pressure of 6000 psi and 1400 C, held at final pressure 4 hrs, and cooled overnight; 98+% theoretical density; expansion measured in air atm.
15*	14	Wilfong, R.L., Dominques, L.P., Furlong, L.R. and Finlay Son, J.A.	1963	I	298-1274		Specimen prepared from commercial single crystal rods; matured at 1000 C for 1 hr and desiccated; heating rate 5 C per min; zero-point correction of 0.005% determined by graphical extrapolation.
16*	14	Wilfong, R.L. et al.	1963	I	298-1272		The above specimen; expansion measured with increasing temp on second test; zero-point correction of 0.0050% determined by graphical extrapolation.
17*	146	Scheetz, H.	1961	L	298-1273		100 pure specimen.
18	147	Merryman, R.G.	1964	X	298-1275		Lattice parameter at 25 C 4.21283 Å; zero-point correction of 0.007% determined by graphical extrapolation.
19	147	Merryman, R.G.	1964	X	298-1205		0.3 Ca, 0.03 Si, 0.02 Ti, Mn, Fe each, 0.01 B, 0.005 Cr, 0.003 Zn, 0.002 Al, 0.001 K, V, Ni, Cu, Sr, Cd, Sn, Ba, Pb each, trace Na, Bi, Co, Mo, Li, Be, Ag; powdered specimen; -325 mesh; expansion measured with gold internal standard; lattice parameter at 25 C 4.21282 Å; zero-point correction of 0.005% determined by graphical extrapolation.

*Not shown in figure.

SPECIFICATION TABLE 61. THERMAL LINEAR EXPANSION OF MAGNESIUM OXIDE MgO (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
20*	15	Klein, D.J.	1958	X	303-1318		Polycrystalline specimen; avg grain size 55 μ; 0.125 x 0.25 x 1.5 in.; obtained from Norton Co; bulk density 3.32 g cm^{-3}.
21*	17	Lukin, E.S. and Polyboyarinov, D.N.	1963	L	293-2273		100 pure specimen; 4 x 4 x 20 mm; prepared from commercial magnesia, pressed at 1000 Kg cm^{-2}, fired at 1950 C; heating rate 5-8 C per min; expansion measured in vacuum furnace.
22*	70	Engberg, C.J. and Zehms, E.H.	1959	T	297-2265	Sample No. CJ-6	Specimen prepared by cold pressing and sintering in oxidizing atm at 1750 C; density 3.22 g cm^{-3}; expansion measured in argon atm.
23*	70	Engberg, C.J. and Zehms, E.H.	1959	T	2265-303		The above specimen; expansion measured with decreasing temp; zero-point correction of 0.18%.
24*	40	Ebert H. and Tingwaldt, C.	1936	T	573-2073		No details given.
25	148	Ballard, S.S. and Browder, J.S.	1966	I	273-333	Irtran 5	Infrared optical specimen; microcrystalline; obtained from Eastman Kodak Co. of N.Y.; hot-pressed; density 3.58 g cm^{-3}; reported error < 2.0%.
26*	149	Browder, J.S. and Ballard, S.S.	1969	E	65-310	Irtran 5	Microcrystalline specimen; obtained from Eastman Kodak Co. of N.Y.; hot-pressed.
27*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-1858	HP-152	99.5 pure; polycrystalline specimen; grain size 30±3 μ; 3 in. long; obtained from Fisher Scientific Co.; electronic, grade M-300; hot-pressed at 3500 psi, 1280 C for 30 min in argon atm; 96+% theoretical density; expansion measured in air atm on first test.
28*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-2072	HP-152	The above specimen; final grain size 50±5 μ; expansion measured on second test.
29*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-2309	HP-152	The above specimen; final grain size 78±9 μ; expansion measured on third test.
30*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-2423	HP-152	The above specimen; grain size initial 78±9 μ, final 161±42 μ; 96.5% theoretical density; expansion measured on fourth test.
31*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-1736	HP-111	99.5 pure; polycrystalline specimen; grain size 6.3 ± 5 μ; obtained from Fisher Scientific Co.; hot-pressed 3500 psi, 1280 C 30 min in argon atm; 96+% theoretical density; expansion measured in carbonaceous argon atm.
32*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-2273	HP-111	The above specimen; final grain size 80.0 ± 8 μ; expansion measured on second test.
33*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-2518	HP-111	The above specimen; final grain size 152 ±16 μ; expansion measured on third test.
34*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-2585	HP-111	The above specimen; final grain size 158 ±16 μ; expansion measured on fourth test.
35*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-2073	LA-5	99.5 pure; polycrystalline specimen; grain size 74±7 μ; obtained from Norton Co.; 200-mesh fused; milled 54 hrs, isostatically pressed at 30 000 psi in air atm; fired at 1750 C, 24 hrs soak; 91.5% theoretical density; expansion measured in air atm.
36*	23	Nielsen, T.H. and Leipold, M.H.	1962	L	673-2428	LA-5	The above specimen; grain size 98 ±10 μ; 93.3% theoretical density; expansion measured on second test.
37	150	Vaughan, D.A. and Schwartz, C.M.	1962	X	304-1345		Expansion measured in air atm; lattice parameter at 31 C 4.212 Å.
38	150	Vaughan, D.A. and Schwartz, C.M.	1962	X	304-1662		Expansion measured in vacuum; lattice parameter at 31 C 4.212 Å.

* Not shown in figure.

SPECIFICATION TABLE 61. THERMAL LINEAR EXPANSION OF MAGNESIUM OXIDE MgO (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
39 *	151	White, H.E.	1938	L	293-1273	Columnar crystals	96.21 MgO, 1.82 CaO, 1.31 SiO_2; specimen cut from solid electrically fused sample; specific gravity 3.585.
40 *	151	White, H.E.	1938	L	293-1273	Stalactite	Specimen cut from solid; electrically fused.
41 *	151	White, H.E.	1938	L	293-1273	Platy crystals	Similar to the above specimen; specific gravity 3.573.
42	152	Campbell, W.J.	1962	X	543-1658	M-300	98.0 MgO, 0.10 SiO_2, 0.03 Fe, 0.013 S, 0.01 Ca; obtained from Fisher Scientific; prepared by Norton Chemical Co; powder mixed with xylene, painted on 1 mm platinum wire, heated at 1073 K 1 hr in air atm; expansion measured at Battelle Memorial Inst. by C.F. Lucks, C.M. Schwartz and D.A. Vaughan; zero-point correction of 0.007% determined by graphical extrapolation.
43	152	Campbell, W.J.	1962	X	395-1473		Similar to the above specimen; except in form of thin rod; expansion measured at B.S.A. Group Research Centre, Birmingham, England by J.A. Brand and H.J. Goldschmidt; zero-point correction of 0.007% determined by graphical extrapolation.
44	152	Campbell, W.J.	1962	X	436-695		Similar to the above specimen; except mounted on Pyrex shaft; expansion measured at Indian Inst. of Science by R.S. Krishvian and M.A. Viswamivra; zero-point correction of 0.007% determined by graphical extrapolation.
45	152	Campbell, W.J.	1962	X	348-788		Similar to the above specimen; except expansion measured at Instituut voor Kristalfysica by G. Boom and W.G. Perdok; zero-point correction of 0.007% determined by graphical extrapolation.
46	152	Campbell, W.J.	1962	X	388-1213		Similar to the above specimen; except expansion measured with gold internal standard at Los Alamos Scientific Laboratory by R.G. Merryman and C.P. Kempter; zero-point correction of 0.007% determined by graphical extrapolation.
47	152	Campbell, W.J.	1962	X	348-540		Similar to the above specimen; except expansion measured with $CuK\alpha_1$, $CuK\alpha_2$, and $CuK\beta_1$ radiations at University College of Science, Osmania University, India by V.T. Deshpande, D.B. Sirdeshmukh and V.M. Mudholker; zero-point correction of 0.007% determined by graphical extrapolation.
48	152	Campbell, W.J.	1962	X	1223-2273		Similar to the above specimen; except expansion measured at AVCO Corp., Wilmington, Mass. by R.E. Dreikorn; zero-point correction of 0.007% determined by graphical extrapolation.
49	152	Campbell, W.J.	1962	X	527-1611		Similar to the above specimen; except expansion measured with platinum internal standard at (College Park Metallurgy Research Center) Bureau of Mines by C. Grain, S. Stecura and W.J. Campbell; zero-point correction of 0.007% determined by graphical extrapolation.
50	152	Campbell, W.J.	1962	X	383-1061		Similar to the above specimen; except expansion measured at University School of Science, Gujarat University, India by P.D. Pathak; zero-point correction of 0.01% determined by graphical extrapolation.
51	152	Campbell, W.J.	1962	X	373-1533		Similar to the above specimen; except expansion measured with silver or platinum internal standard at National Bureau of Standards by L.H. Bolz and F.A. Mauer; zero-point correction of 0.007% determined by graphical extrapolation.
52 *	152	Campbell, W.J.	1962	X	495-1158		Similar to the above specimen; except expansion measured at Pennsylvania State University by H. McKinstry; zero-point correction of 0.007% determined by graphical extrapolation.

*Not shown in figure.

SPECIFICATION TABLE 61. THERMAL LINEAR EXPANSION OF MAGNESIUM OXIDE MgO (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
53*	152	Campbell, W.J.	1962	X	573-1273		Similar to the above specimen; except expansion measured with $CuK\alpha_1$ radiation at United Aircraft Corp. Research Laboratories, East Hartford, Conn. by F.S. Galasso and W.R. Diefenderfer; zero-point correction of 0.007% determined by graphical extrapolation.
54*	152	Campbell, W.J.	1962	L	473-1273		Similar to the above specimen; except calcined at 1273 K 6 hrs; sieved at 60-mesh and isostatically pressed; latex bags 0.64 cm dia, 15 cm long, filled evacuated, sealed and pressed at 15 000 psi; fired to 1200 C 4 hrs, held at 1200 C 16 hrs, to 1600 C 3 hrs, held at 1600 C 22 hrs; expansion measured at Autonutronic Ford Motor Co., Newport Beach, Calif. by W.M. Fassell, Jr. and T.M. Place, Jr.; zero-point correction of 0.007% determined by graphical extrapolation.
55*	152	Campbell, W.J.	1962	L	380-1680		Similar to the above specimen; except expansion measured at State University of New York, Alfred, N.Y., by W.B. Crandall; zero-point correction of 0.007% determined by graphical extrapolation.
56*	152	Campbell, W.J.	1962	L	373-1173		Similar to the above specimen; except isostatically pressed; expansion measured at Battelle Memorial Institute by C.F. Lucks and H.W. Deem; zero-point correction of 0.007% determined by graphical extrapolation.
57*	152	Campbell, W.J.	1962	L	373-1673		Similar to the above specimen; except isostatically pressed; expansion measured at (College Park Metallurgy Research Center) Bureau of Mines by J. Finlayson and L. P. Dominques; zero-point correction of 0.01% determined by graphical extrapolation.
58*	152	Campbell, W.J.	1962	L	423-1423		Similar to the above specimen; except isostatically pressed; expansion measured at Bureau of Mines, Norris, Tenn. by P.G. Pigott; zero-point correction of 0.007% determined by graphical extrapolation.
59*	152	Campbell, W.J.	1962	I	323-1173		Similar to the above specimen; except heating rate 6 C per min; expansion measured at College Park Metallurgy Research Center, Bureau of Mines by J. Finlayson and L.P. Dominques; zero-point correction of 0.007% determined by graphical extrapolation.
60*	153	Lieberman, A. and Crandall, W.B.	1952	L	293-1673		Single crystal specimen; supplied by the Norton Co.
61*	154	Rigby, G.R. and Green, A.T.	1941	L	373-1373		No details given; zero-point correction of 0.082% determined by graphical extrapolation.
62*	95	Williams, R.M.	1967	L	302-1250	G.E. Blend 2109	99^+ MgO, 0.6 SiO_2; bar specimen 0.95 x 1.27 x 5.93 cm; electrically fused periclase; prepared from General Electric Blend 2109; pressed at 5000, 10 000 and 15 000 psi; fired at 1.873 K for 2 hrs after slow heating.
63	155	Zimmerman, W.F. and Allen, A.W.	1956	X	303-1456		High purity fused specimen; expansion measured with $CoK\alpha$ radiation in back-reflection high temperature camera; zero-point correction of 0.013% determined by graphical extrapolation.
64*	155	Zimmerman, W.F. and Allen, A.W.	1956	X	296-1466		Similar to the above specimen; except obtained from Washington dead burned magnesite; zero-point correction of 0.003% determined by graphical extrapolation.
65*	156	Campbell, W.J., Stecura, S. and Grain, C.	1961	X	516-1467		Expansion measured in Furnace 1; reported error < 0.1%.

*Not shown in figure.

SPECIFICATION TABLE 61. THERMAL LINEAR EXPANSION OF MAGNESIUM OXIDE MgO (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
66 *	156	Campbell, W.J., Stecura, S. and Grain, C.	1961	X	415-1559		The above specimen; expansion measured in Furnace 2; reported error < 1.0%.
67 *	157	Pathak, P.D., Pandya, N.V. and Ghadiali, M.P.	1962	X	301-1065		No details given; zero-point correction of 0.01% determined by graphical extrapolation.
68	74	Beals, R.J. and Cook, R.L.	1957	X	293-1472		Reagent grade, cubic structured powder specimen.
69	25	Baldock, P.J., Spindler, W.E. and Baker, T.W.	1968	X	285-1617	Specimen 1	99.9 pure; powder specimen; cold-pressed to brick and sintered at 2073 K for 4 hrs.
70 *	25	Baldock, P.J. et al.	1968	X	321-2031	Specimen 2	Similar to the above specimen.
71 *	25	Baldock, P.J. et al.	1968	X	322-574	Specimen 2	The above specimen.
72 *	25	Baldock, P.J. et al.	1968	X	299-2009	Specimen 3	Similar to the above specimen.
73 *	25	Baldock, P.J. et al.	1968	X	293-590	Specimen 3	The above specimen.
74 *	88	Ohba, H., Hiragushi, K. and Nakashima, C.	1965	X	1073-1773		Specimen prepared from decomposed product of Dolomite in air atm; expansion measured in d(200) direction; this curve is reported using the first given temp as ref temp at which $\Delta L/L_o = 0$; interplanar spacing at 1073 K 2.129 Å.
75	28	Merritt, G.E.	1926	I	298-1039		95.0 MgO, impurities SiO_2, CaO, Al_2O_3, and Fe_2O_3; obtained from Norton Co.; prepared by fusing magnesite in electric furnace at some temp above 2500 C; zero-point correction of 0.005% determined by graphical extrapolation.
76 *	158	Rigby, G.R., Lovell, H.B. and Green, A.T.	1945		373-1273		Specimen 2 cm dia, 5 cm long; specific gravity 3.58; zero-point correction of 0.1 % determined by graphical extrapolation.
77 *	159	Chow, A.T-S	1962	G	298-873		Thin rectangle specimen; 1 in. long; zero-point correction of 0.006% determined by graphical extrapolation.
78 *	70	Wisely, H.R.	1962	L	373-973		Bar specimen; 0.25 x 0.375 x 2 in.; prepared by pressing under pressure 26 000 psi, sintered for 16 hrs in air atm; reported error ±1%.
79 *	33	Kirchner, H.P. and Gruver, R.M.	1965	X	298-1273		Powdered specimen; zero-point correction of 0.004% determined by graphical extrapolation.
80	160	Schaake, H.F.	1969	X	4.2-298		Single crystal specimen obtained from Harshaw; annealed at 1173 K for 16 hrs; lattice parameter at 25 C 4.2110 Å.
81 *	161	Sharma, S.S.	1950	I	323-987		Synthetically grown specimen.
82 *	162	Paladino, A.E. and Snider, C.R.	1970	L	318-1201		Reagent grade; polycrystalline specimen; prepared by hot-pressing at 6000 psi, 1873 K in graphite dies at 10^{-4} torr for 30 min; annealed at 1723 K for 20 hrs; zero-point correction of -0.028% determined by graphical extrapolation.
83	129	Bickelhaupt, R.E.	1969	X	293-1485		Specimen prepared by firing in vacuum at 1473 K for 50 hrs, firing in helium at 1873 K for 4 hrs; quenched; expansion measured in vacuum < 1 μ Hg.
84 *	129	Bickelhaupt, R.E.	1969	X	480-1504		The above specimen; expansion measured on second test.
85 *	123	Saito, T.	1967	X	293-1329		Standard specimen; expansion measured along a-axis.
86 *	163	Skinner, B.J.	1957	X	283-976		Synthetical specimen; obtained from Norton Co.; lattice parameter at 21.0 C 4.21160 Å.
87 *	164	Burdick, M.D., Zweig, B. and Moreland, R.E.	1951	L	373-1643		Single crystal specimen; expansion measured in vacuum.

*Not shown in figure.

SPECIFICATION TABLE 61. THERMAL LINEAR EXPANSION OF MAGNESIUM OXIDE MgO (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
88*	336	Kamenetskii, A.B., Gol'ko, N.V., and Gladkaga, N.V.	1970	X	373-1473		96.25 MgO, 1.8 CaO, 1.17 SiO_2, 0.4 Al_2O_3, 0.30 Fe_2O_3; specimen prepared by semidry pressing finely dispersed powder of grain size <2μ at 1000 kg cm^{-2} and fired at 2023 K; data from smoothed curve.
89*	633	Ganesan, S.	1961	I	140-284.5		Accuracy better than 3%.
90*	503	Burk, M.	1961	L	73-293	MP-99-C	99 MgO; specimen 6 in. long, 0.125 in. in diameter; heated by ambient air to room temperature; firing temperature 1700 C, density 2.9-3.0 g cm^{-3} at room temperature; porosity 20%.
91*	503	Burk, M.	1961	L	73-293	MP-99-I	Similar to the above specimen except density 3.10 g cm^{-3} at room temperature; porosity 15%.
92*	634	Nielsen, T.H. and Leipold, M.H.	1962	X	298-2573		Specimen 99.5 pure; HP-152 and HP-111; Fisher Scientific Co. electronic grade M-300; hot pressed 3500 psi, 1280 C for 30 min; atmosphere argon.
93	634	Nielsen, T.H. and Leipold, M.H.	1962	X	298-2373		Specimen LA-5-Norton Co. 200 mesh fused; milled 54 hr isostatically pressed at 30,000 psi; firing: 1750 C, 24 hr soak; atmosphere air.
94*	587	Smith, D.K. and Leider, H.R.	1968	X	19-297		Specimen 99.91 MgO, 0.01 Si, 0.02 Fe, 0.0005 Pb, 0.01 Al, 0.05 Ca, 0.002 Mn; obtained from Semi-Elements Inc.; in the form of (100) plates cleaned from large crystals; indicated error range ±0.002 Å; samples cleaned to 0.05 cm thick.
95*	632	Bridgman, P.W.	1932		303,348		Artificial transparent crystal specimen; 1.0 cm long.

* Not shown in figure.

DATA TABLE 61. THERMAL LINEAR EXPANSION OF MAGNESIUM OXIDE MgO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*, ‡	
4	-0.134
43	-0.134
71	-0.132
102	-0.128
132	-0.119
266	-0.027
286	-0.007
293	0.000
CURVE 2*	
298	0.007
573	0.372
873	0.783
1173	1.223
1473	1.770
1773	2.368
CURVE 3*	
302	0.002
354	0.010
411	0.045
488	0.121
556	0.229
612	0.339
655	0.447
669	0.501
695	0.544
719	0.540
734	0.507
749	0.477
779	0.512
881	0.647
1021	0.847
1165	1.044
1273	1.209
1325	1.253
1378	1.270
1425	1.256
1454	1.201
1469	1.106
1479	1.026
1501	0.882
1520	0.734
1531	0.645
CURVE 3 (cont.)*	
1545	0.576
1561	0.496
1575	0.445
1588	0.400
1606	0.334
1626	0.256
1649	0.160
1664	0.072
1682	-0.048
1714	-0.198
1733	-0.351
1748	-0.483
1756	-0.610
1764	-0.734
1768	-0.851
1773	-1.034
CURVE 4	
298	0.005
389	0.105
514	0.252
576	0.329
640	0.418
717	0.527
787	0.639
843	0.706
900	0.798
910	0.804
969	0.900
1047	1.010
1138	1.158
1205	1.257
CURVE 5*	
299	0.006
474	0.211
675	0.484
878	0.752
1078	1.051
1280	1.368
CURVE 6*	
293	0.000
1073	1.092
CURVE 7*	
344	0.056
366	0.083
477	0.216
588	0.348
700	0.484
810	0.615
883	0.703
CURVE 8	
273	-0.025
299	0.008
481	0.229
689	0.500
897	0.794
1105	1.100
1313	1.430
1521	1.810
1677	2.090
CURVE 9*	
300	0.009
866	0.794
CURVE 10*	
366	0.068
478	0.191
588	0.330
699	0.479
781	0.600
CURVE 11*	
293	0.000
323	0.012
373	0.073
423	0.135
473	0.196
523	0.260
573	0.325
623	0.395
673	0.462
723	0.535
773	0.607
823	0.680
CURVE 11 (cont.)*	
873	0.752
923	0.825
973	0.900
1023	0.975
1073	1.050
1123	1.125
1173	1.200
1223	1.275
1273	1.350
CURVE 12*	
573	0.36
773	0.60
973	0.90
1173	1.20
1353	1.52
1553	1.85
1753	2.20
1953	2.60
2063	2.85
CURVE 13*	
294	0.00
541	0.26
786	0.58
1123	1.05
1122	1.04
1338	1.35
1499	1.59
1744	1.93
1922	2.18
2110	2.45
2260	2.64
2435	2.79
2833	2.72
2844	2.10
2872	1.20
2983	0.70
CURVE 14*, ‡	
473	0.192
673	0.405
873	0.644
CURVE 14 (cont.)*, ‡	
1073	0.895
1273	1.155
CURVE 15*	
298	0.0050
374	0.0884
474	0.2105
577	0.3445
676	0.4778
771	0.6102
875	0.7583
973	0.9026
1076	1.0585
1172	1.2070
1274	1.3665
CURVE 16*	
298	0.0050
377	0.0910
479	0.2146
573	0.3379
671	0.4696
768	0.6050
874	0.7573
970	0.8990
1073	1.0533
1171	1.2052
1272	1.3624
CURVE 17*	
298	0.007
673	0.513
1273	1.392
CURVE 18	
298	0.007*
365	0.103
372	0.146
476	0.280
585	0.450
653	0.567
666	0.560
CURVE 18 (cont.)	
775	0.645
861	0.786
931	0.863
972	0.881
977	0.904
989	0.917
1018	0.971
1077	1.053
1088	1.052
1125	1.110
1148	1.120
1161	1.134
1275	1.301
CURVE 19	
298	0.005*
389	0.105*
514	0.252
576	0.328*
640	0.418
717	0.527*
787	0.639*
843	0.706*
900	0.798
910	0.804*
969	0.900*
1047	1.011
1138	1.157*
1205	1.256*
CURVE 20*	
303	0.03
523	0.30
753	0.58
1023	1.16
1123	1.56
1318	1.67
CURVE 21*	
293	0.000
1273	1.313
1373	1.490
1473	1.652

* Not shown in figure.

‡ Author's data for coefficient of expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 61. THERMAL LINEAR EXPANSION OF MAGNESIUM OXIDE MgO (continued)

T	$\Delta L/L_0$
CURVE 21 (cont.)*	
1573	1.830
1673	2.001
1773	2.176
1873	2.354
1973	2.520
2073	2.706
2173	2.876
2273	3.069
CURVE 22*	
297	0.00
1153	0.96
1185	1.06
1239	1.13
1287	1.19
1353	1.28
1405	1.38
1455	1.46
1513	1.52
1545	1.60
1629	1.72
1657	1.76
1713	1.85
1787	1.96
1837	2.04
1885	2.13
1907	2.20
2023	2.30
2049	2.34
2101	2.41
2145	2.46
2265	2.55
CURVE 23*	
2265	2.73
2129	2.69
2017	2.56
2013	2.38
1981	2.29
1905	2.20
1865	2.11
1797	2.00
1753	1.92
1697	1.80
1653	1.68
1597	1.61

T	$\Delta L/L_0$
CURVE 23 (cont.)*	
1531	1.52
1457	1.42
1433	1.36
1371	1.29
1321	1.20
1265	1.12
1209	1.03
1157	0.96
303	0.00
CURVE 24*	
573	0.360
773	0.630
973	0.930
1173	1.235
1273	1.390
1373	1.550
1573	1.885
1773	2.260
1973	2.655
2073	2.875
CURVE 25	
273	-0.023
298	0.006*
333	0.046
CURVE 26*,‡	
65	-0.137
70	-0.136
80	-0.135
90	-0.134
100	-0.132
110	-0.130
120	-0.127
130	-0.123
140	-0.119
150	-0.115
160	-0.109
170	-0.104
180	-0.097
190	-0.091
200	-0.084
210	-0.076
220	-0.068

T	$\Delta L/L_0$
CURVE 26 (cont.)*,‡	
230	-0.060
240	-0.051
250	-0.042
260	-0.033
270	-0.023
280	-0.013
290	-0.003
300	0.007
310	0.018
CURVE 27*	
673	0.480
873	0.774
1073	1.100
1273	1.460
1473	1.840
1673	2.240
1858	2.620
CURVE 28*	
673	0.485
873	0.780
1073	1.300
1273	1.440
1473	1.800
1673	2.170
1873	2.580
2072	3.020
CURVE 29*	
673	0.492
873	0.790
1073	1.110
1273	1.460
1473	1.810
1673	2.190
1873	2.580
2073	2.990
2146	3.150
2273	3.560
2309	3.700
CURVE 30*	
673	0.488

T	$\Delta L/L_0$
CURVE 30 (cont.)*	
873	0.782
1073	1.100
1273	1.440
1473	1.790
1673	2.170
1873	2.560
2073	2.950
2273	3.360
2348	3.520
2423	3.730
CURVE 31*	
673	0.489
873	0.775
1073	1.080
1273	1.420
1473	1.790
1673	2.210
1736	2.360
CURVE 32*	
673	0.478
873	0.771
1073	1.090
1273	1.430
1473	1.790
1673	2.190
1873	2.600
2073	3.050
2173	3.260
2273	3.440
CURVE 33*	
673	0.484
873	0.787
1073	1.110
1273	1.460
1473	1.820
1673	2.210
1873	2.600
2073	3.010
2273	3.430
2473	3.850
2518	3.950

T	$\Delta L/L_0$
CURVE 34*	
673	0.499
873	0.798
1073	1.120
1273	1.460
1473	1.830
1673	2.230
1873	2.650
2073	3.080
2273	3.530
2473	3.990
2585	4.270
CURVE 35*	
673	0.479
873	0.757
1073	1.060
1273	1.380
1473	1.730
1673	2.110
1873	2.500
2073	2.900
CURVE 36*	
673	0.492
873	0.781
1073	1.090
1273	1.420
1473	1.760
1673	2.110
1873	2.470
2073	2.850
2273	3.230
2428	3.530
CURVE 37	
304	0.009
492	0.280
705	0.525
714	0.544
957	0.881
1173	1.142
1345	1.410

T	$\Delta L/L_0$
CURVE 38	
304	-0.009*
545	0.330
675	0.482
814	0.651
887	0.774
913	0.774
1041	0.992
1137	1.142
1233	1.265
1355	1.448
1432	1.538
1662	1.883
CURVE 39*	
293	0.0000
323	0.0207
373	0.0752
423	0.1270
473	0.1832
523	0.2430
573	0.3720
623	0.3808
673	0.4443
723	0.5089
773	0.5865
823	0.6571
873	0.7355
923	0.8071
973	0.8801
1023	0.9549
1073	1.0249
1123	1.0970
1173	1.1680
1223	1.2530
1273	1.3334
CURVE 40*	
293	0.0000
323	0.0227
373	0.0760
423	0.1455
473	0.1892
523	0.2470
573	0.3170
623	0.3808
673	0.4474

* Not shown in figure.

‡ Author's data for coefficient of expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 61. THERMAL LINEAR EXPANSION OF MAGNESIUM OXIDE MgO (continued)

T	$\Delta L/L_0$
CURVE 40 (cont.)*	
723	0.5223
773	0.5862
823	0.6564
873	0.7250
923	0.8035
973	0.8764
1023	0.9459
1073	1.0261
1123	1.0965
1173	1.1690
1223	1.2610
1273	1.3314
CURVE 41*	
293	0.0000
323	0.0187
373	0.0593
423	0.0927
473	0.1555
523	0.2458
573	0.3050
623	0.3810
673	0.4535
723	0.5207
773	0.5822
823	0.6436
873	0.7281
923	0.8010
973	0.8694
1023	0.9348
1073	1.0010
1123	1.0661
1173	1.1472
1223	1.2284
1273	1.3034
CURVE 42	
543	0.344
678	0.489
813	0.658
893	0.791
1043	1.002
1133	1.166
1233	1.282
1353	1.479
1428	1.562
1658	1.919

T	$\Delta L/L_0$
CURVE 43	
395	0.126
469	0.199
583	0.373
677	0.491*
870	0.769
1044	1.007*
1139	1.132
1233	1.277
1352	1.433
1473	1.592
CURVE 44	
433	0.178
540	0.334
609	0.424
695	0.534
CURVE 45	
348	0.062
403	0.137
503	0.273
593	0.376
788	0.632
CURVE 46	
388	0.108*
638	0.421
788	0.642*
901	0.801*
965	0.903
1145	1.161
1213	1.260
CURVE 47	
348	0.063*
396	0.115
473	0.215
540	0.312
CURVE 48	
1223	1.281
1343	1.495
1963	2.396
2273	2.824*

T	$\Delta L/L_0$
CURVE 49	
527	0.268
661	0.444
796	0.627
895	0.783*
1021	0.964
1149	1.149
1289	1.398
1404	1.565
1533	1.769
1611	1.901
CURVE 50	
383	0.14
481	0.26
568	0.36
733	0.57
825	0.69
964	0.95
1061	1.09
CURVE 51	
373	0.088
475	0.223
576	0.351
721	0.513
874	0.74
925	0.826
1028	0.966
1103	1.101
1328	1.400
1533	1.757
CURVE 52*	
495	0.237
572	0.329
665	0.458
786	0.617
877	0.750
1088	1.082
1158	1.173
CURVE 53*	
573	0.355
873	0.778
1273	1.333

T	$\Delta L/L_0$
CURVE 54*	
473	0.187
573	0.307
673	0.443
773	0.579
873	0.717
973	0.863
1073	1.004
1173	1.152
1273	1.300
CURVE 55*	
380	0.090
525	0.276
661	0.465
823	0.689
987	0.923
1158	1.178
1306	1.414
1457	1.704
1593	1.882
1680	2.017
CURVE 56*	
373	0.088
573	0.330
673	0.461
773	0.601
973	0.887
1073	1.036
1173	1.189
CURVE 57*	
373	0.07
523	0.21
623	0.36
723	0.51
923	0.81
1123	1.14
1323	1.45
1473	1.69
1573	1.86
1673	2.00
CURVE 58*	
423	0.094

T	$\Delta L/L_0$
CURVE 58 (cont.)*	
523	0.207
623	0.337
723	0.476
823	0.619
923	0.771
1023	0.927
1223	1.247
1323	1.417
1423	1.573
CURVE 59*	
323	0.029
423	0.135
573	0.320
723	0.543
873	0.784
1023	1.004
1173	1.245
CURVE 60*	
293	0.000
373	0.071
423	0.133
473	0.202
523	0.264
573	0.320
623	0.403
673	0.471
723	0.552
773	0.611
823	0.690
873	0.761
923	0.832
973	0.913
1023	0.982
1073	1.051
1123	1.120
1173	1.200
1223	1.271
1273	1.344
1323	1.432
1373	1.503
1423	1.573
1473	1.641
1523	1.720
1573	1.792
1623	1.851

T	$\Delta L/L_0$
CURVE 60 (cont.)*	
1673	1.922
CURVE 61*	
373	0.082
473	0.202
573	0.332
673	0.465
773	0.609
873	0.757
973	0.882
1073	1.022
1173	1.182
1273	1.209
1373	1.532
CURVE 62*	
302	0.01
373	0.10
473	0.22
573	0.36
673	0.50
773	0.64
873	0.77
973	0.93
1073	1.08
1173	1.24
1250	1.35
CURVE 63	
303	0.013*
472	0.226
684	0.513
857	0.737
1061	1.034
1238	1.269*
1456	1.577
CURVE 64*	
296	0.003
482	0.205
675	0.461
882	0.727
1068	0.983
1266	1.260
1466	1.579

* Not shown in figure.

DATA TABLE 61. THERMAL LINEAR EXPANSION OF MAGNESIUM OXIDE MgO (continued)

T	$\Delta L/L_0$
CURVE 65*	
516	0.300
522	0.296
759	0.623
775	0.642
967	0.926
967	0.946
1057	1.066
1245	1.376
1260	1.398
1329	1.497
1449	1.768
1467	1.780
CURVE 66*	
415	0.191
570	0.374
587	0.405
668	0.503
711	0.557
754	0.607
809	0.701
902	0.831
1038	1.029
1108	1.155
1165	1.252
1212	1.306
1298	1.439
1309	1.506
1348	1.566
1404	1.663
1422	1.685
1460	1.771
1538	1.926
1559	1.949
CURVE 67*	
301	0.01
383	0.13
484	0.24
573	0.34
664	0.46
733	0.56
829	0.68
878	0.79
967	0.94
1065	1.08
CURVE 68	
293	0.000
483	0.264*
678	0.497*
873	0.764
1073	1.032
1268	1.324
1472	1.550
CURVE 69	
285	0.038
530	0.299
700	0.532
895	0.838
1119	1.175
1420	1.678
1617	1.983
CURVE 70*	
321	0.049
391	0.121
483	0.199
567	0.289
821	0.672
1040	1.004
1272	1.386
1502	1.771
1614	1.956
1832	2.393
2031	2.649
CURVE 71*	
322	0.042
399	0.126
487	0.221
574	0.311
CURVE 72*	
299	-0.033
1773	2.189
2009	2.386
CURVE 73*	
293	0.016
CURVE 73 (cont.)*	
294	0.007
299	0.005
336	0.045
344	0.057
378	0.102
394	0.133
433	0.161
451	0.180
470	0.218
525	0.278
590	0.363
CURVE 74*,‡	
1073	0.000
1173	0.001
1273	0.003
1373	0.005
1473	0.006
1573	0.008
1673	0.009
1773	0.012
CURVE 75	
298	0.005*
418	0.131
511	0.249
602	0.368
687	0.482
769	0.605
848	0.717
925	0.832
998	0.942
1039	1.003
CURVE 76*	
373	0.07
473	0.19
573	0.32
673	0.45
773	0.60
873	0.75
973	0.87
1073	1.01
1173	1.17
1273	1.34
CURVE 77*	
298	0.006
323	0.035
373	0.083
423	0.113
473	0.129
523	0.164
573	0.210
623	0.249
673	0.305
723	0.357
773	0.410
823	0.467
873	0.521
CURVE 78*	
373	0.101
673	0.479
973	0.905
CURVE 79*	
298	0.004
473	0.211
673	0.481
873	0.744
1073	1.044
1273	1.362
CURVE 80	
4.2	-0.135
20	-0.135
40.5	-0.134
77.4	-0.133
110	-0.128
150	-0.111
194.5	-0.088
240	-0.047
273	0.019
298	0.006*
CURVE 81*,‡	
323.5	0.034
364.3	0.081
403.8	0.127
441.9	0.172
CURVE 81 (cont.)*,‡	
478.8	0.217
514.7	0.262
550.1	0.307
584.9	0.351
619.9	0.397
653.0	0.440
690.0	0.490
730.1	0.546
769.1	0.601
807.4	0.656
845.2	0.711
882.6	0.766
919.4	0.821
955.4	0.877
987.4	0.926
CURVE 82*	
318	0.024
382	0.086
469	0.181
572	0.312
670	0.440
774	0.589
871	0.727
901	0.772
970	0.875
1083	1.046
1173	1.182
1201	1.222
CURVE 83	
293	0.000*
480	0.236
659	0.497
878	0.797
1080	1.118
1273	1.433
1485	1.839
CURVE 84*	
480	0.227
673	0.497
870	0.786
1059	1.060
1504	1.879
CURVE 85*	
293	0.000
375	0.093
427	0.157
475	0.215
522	0.298
574	0.343
622	0.411
673	0.482
725	0.550
775	0.616
824	0.679
873	0.752
926	0.824
975	0.886
1026	0.968
1074	1.033
1127	1.109
1179	1.180
1226	1.274
1276	1.353
1329	1.438
CURVE 86*	
283.7	-0.007
294.2	0.000
298.2	0.002
319.7	0.019
349.7	0.047
404.2	0.103
502.7	0.221
593.8	0.336
677.4	0.448
785.2	0.598
875.0	0.721
976.3	0.867
CURVE 87*	
373	0.09
473	0.20
573	0.32
673	0.47
773	0.61
873	0.75
973	0.89
1073	1.04
1173	1.19

* Not shown in figure.

‡ Author's data for coefficient of expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 61. THERMAL LINEAR EXPANSION OF MAGNESIUM OXIDE MgO (continued)

T	$\Delta L/L_0$
CURVE 87 (cont.)*	
1273	1.32
1373	1.47
1473	1.61
1573	1.77
1643	1.88
CURVE 88*	
373	0.07
473	0.21
573	0.34
673	0.45
773	0.56
873	0.69
973	0.81
1073	0.94
1173	1.11
1273	1.27
1373	1.43
1473	1.56
CURVE 89*,‡	
141	-0.121
161	-0.111
179	-0.100
195	-0.088
212	-0.075
228	-0.062
240	-0.051
251	-0.041
260	-0.033
272	-0.021
282	-0.011
293	0.000
CURVE 90*	
73	-0.133
123	-0.124
173	-0.099
223	-0.062
273	-0.017
CURVE 91*	
73	-0.133
123	-0.123
173	-0.097
223	-0.059
273	-0.017
CURVE 92*	
298	0.006
673	0.473
1073	1.090
1473	1.815
1873	2.602
2073	3.040
2273	3.463
2373	3.713
2473	3.929
2573	4.241
CURVE 93	
298	0.006*
673	0.484*
1073	1.095*
1473	1.794
1873	2.553
2073	2.955*
2273	3.402*
2373	3.619*
CURVE 94*	
19	-0.131
28	-0.133
40	-0.135
88	-0.138
89	-0.133
98	-0.140
102	-0.126
104	-0.133
109	-0.126
114	-0.128
118	-0.126
133	-0.121
136	-0.121
141	-0.121
141	-0.112
148	-0.116
156	-0.116
158	-0.104
173	-0.104
199	-0.102
231	-0.062
246	-0.050
263	-0.033
276	-0.024
293	0.000
297	0.000
297	0.009
CURVE 95*	
303	0.003
348	0.018

* Not shown in figure.
‡ Author's data for coefficient of expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 61. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MAGNESIUM OXIDE MgO

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

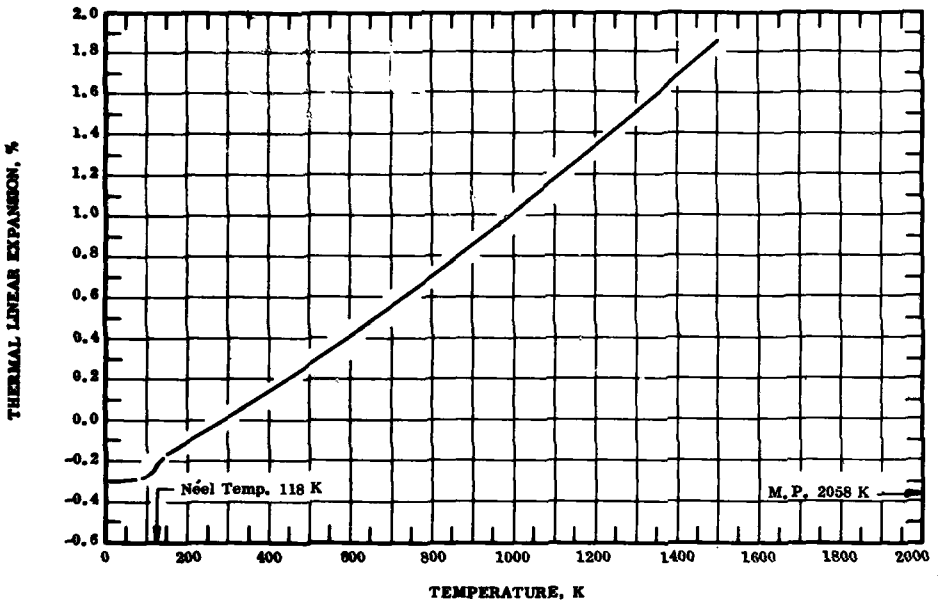
T	α
CURVE 1*,‡	
4	0.00
43	0.14
71	0.83
102	2.11
132	3.88
266	9.73
286	10.44
293	10.50
CURVE 14*,‡	
473	9.65
673	11.65
873	12.28
1073	12.78
1273	13.26
CURVE 26‡	
65	0.61
70	0.78
80	1.14
90	1.58
100	2.10
110	2.61
120	3.20
130	3.86
140	4.37
150	4.95
160	5.48
170	6.00
180	6.49
190	6.95
200	7.39
210	7.80
220	8.20
230	8.50
240	8.80
250	9.10
260	9.40
270	9.70
280	10.00
290	10.20
300	10.40
310	10.60*

T	α
CURVE 81*,‡	
323.5	11.28
364.3	11.45
403.8	11.74
441.9	12.09
478.8	12.39
514.7	12.58
550.1	12.73
584.9	12.88
619.9	13.08
653.0	13.25
690.0	13.65
730.1	14.01
769.1	14.31
807.4	14.52
845.2	14.68
882.6	14.82
919.4	15.14
955.4	15.46
987.4	15.51
CURVE 89‡	
141	4.64
161	5.61
179	6.61*
195	7.42
212	8.10
228	8.66
240	9.00
251	9.33
260	9.62*
272	9.78
282	9.90
293	10.26

* Not shown in figure.

‡ Author's data for coefficient of expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 62R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF MANGANESE MONOXIDE MnO



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
5	-0.300†	0.0
10	-0.300†	2.0
50	-0.291†	3.0
75	-0.280†	8.5
100	-0.248†	15.0
118§	-0.215	26.0
125	-0.182	11.5
150	-0.177	12.0
200	-0.116	12.2
250	-0.054	12.5
293	0.000	12.7
400	0.140	13.3
500	0.275	13.7
600	0.415	14.2
700	0.560	14.6
800	0.710	15.1
900	0.860	15.5
1000	1.020	15.9
1100	1.180	16.2
1200	1.345	16.6
1300	1.508	16.9
1400	1.680	17.2
1500	1.855	17.5

§ Néel temperature.
† Provisional values.

REMARKS

The recommended values are based on the data for pure samples and are considered accurate to within ± 5% at temperatures above 118 K and ± 10% below 118 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.350 + 1.115 \times 10^{-3}\, T + 2.834 \times 10^{-7}\, T^2 - 3.181 \times 10^{-11}\, T^3 \qquad (150\text{–}1500\ K)$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ± 10%.

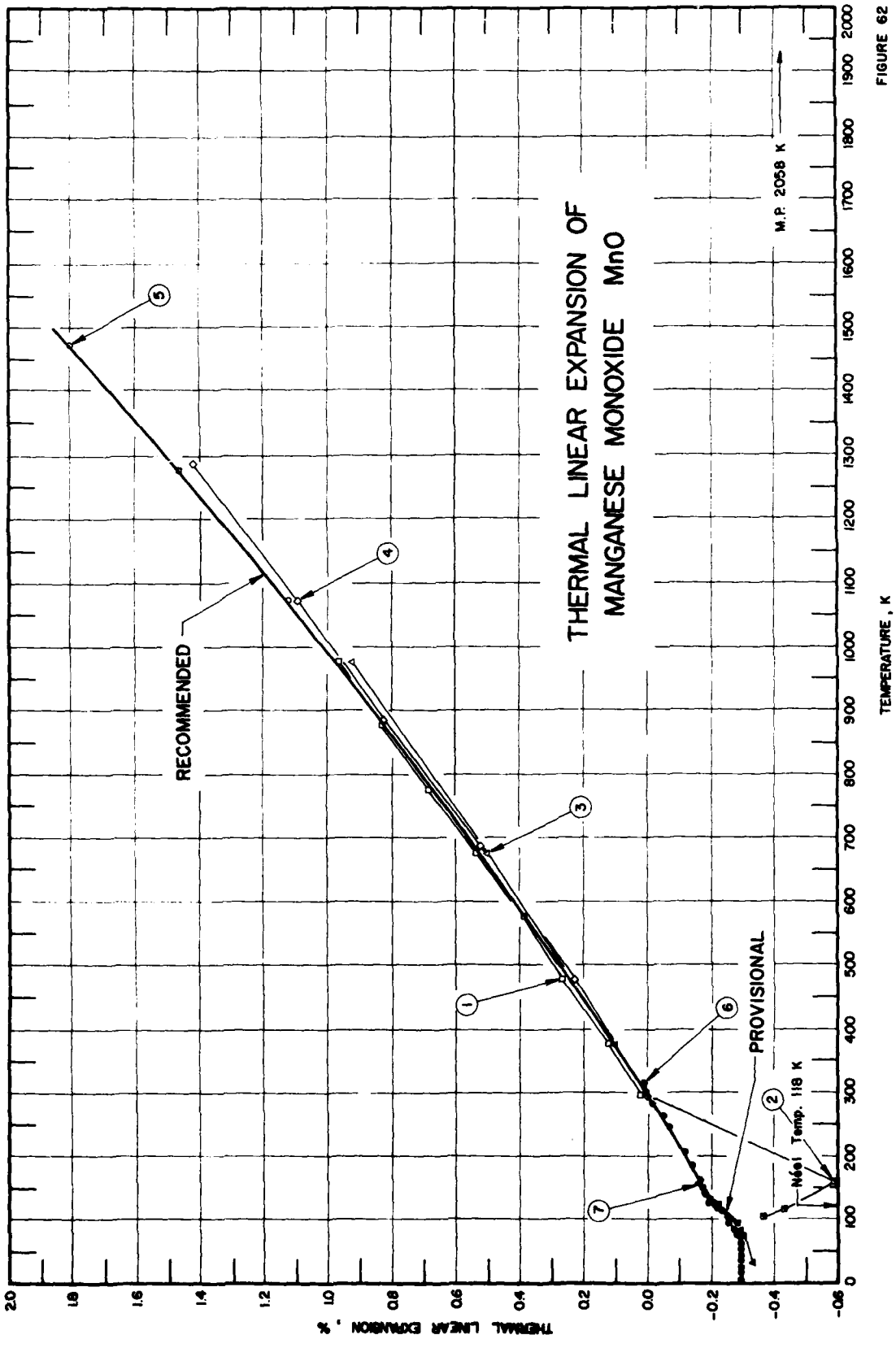

THERMAL LINEAR EXPANSION OF
MANGANESE MONOXIDE MnO
M.P. 2058 K
RECOMMENDED
PROVISIONAL
Néel Temp. 118 K
1
2
3
4
5
6
7
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 62

SPECIFICATION TABLE 62. THERMAL LINEAR EXPANSION OF MANGANESE MONOXIDE MnO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	94	Brooksbank, D. and Andrews, K.W.	1968	X	298-974		Powder specimen; prepared by heating manganese oxalate ($MnC_2O_4 \cdot 2H_2O$) in vacuum up to 1323 K; coated onto hot junction of temperature-measuring thermocouple; expansion measured with CrKα radiation for 4-6 hr; partial oxidation of specimen to Mn_3O_4; lattice parameter reported at 298 K is 4.445 Å ; 4.444 Å at 293 K determined by graphical extrapolation.
2	120	Ellefson, B. S. and Taylor, N.W.	1934	X	104-299		Powder specimen; obtained from Dr. C. G. Mater of Bureau of Mines Pacific Experiment Station, Berkeley, California; lattice constant reported at 104 K is 4.419 Å ; 4.435 Å at 293 K determined by graphical interpolation.
3	128	Wiesly, H.R.	1962	L	373-973		Bar specimen; 1/4 x 3/8 x 2 in.; prepared under pressure 26,000 psi, sintered at 1523 K for 16 hr in H_2/CO_2 ratio of 1/2 atm.
4	129	Bickelhaupt, R.E.	1968	X	293-1280		Specimen prepared by firing at 1473 K for 50 hr in vacuum; then fired at 1873 K for 4 hr in helium atm., quenched; expansion measured in vacuum of <1 μ Hg.
5	129	Bickelhaupt, R. E.	1968	X	474-1474		The above specimen; expansion measured on second test.
6	130	Morosin, B.	1970	X	5-305		Both single crystal and powder specimens obtained from R. Lindsay; expansion measured using CuKα radiation; at helium temperature lattice constant becomes 4.4316 ± 0.0003 Å ; 4.4449 Å at 293K.
7	636	Block, D., Charbit, P., and Georges, R.	1968	X	34-300		Lattice parameter reported at 34 K is 4.4304 Å; 4.4448 Å at 293 K determined by graphical interpolation.

DATA TABLE 62. THERMAL LINEAR EXPANSION OF MANGANESE MONOXIDE MnO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.0225
378	0.1350
477	0.2700
576	0.3825
673	0.5400
777	0.6976
877	0.8326
974	0.9676
CURVE 2	
104	-0.3608
115	-0.4284
160	-0.5862
299	0.0225*
CURVE 3	
373	0.107
673	0.509
973	0.929
CURVE 4	
293	0.000
474	0.237
688	0.525
881	0.824
1077	1.100
1280	1.433
CURVE 5	
474	0.226*
688	0.525*
879	0.833*
1077	1.138
1276	1.475
1474	1.812
CURVE 6	
5	-0.2998
6	-0.2998*
8	-0.2998*
16	-0.2980
27	-0.2951
37	-0.2951
46	-0.2933
51	-0.2913
57	-0.2893*
CURVE 6 (cont.)	
64	-0.2904
74	-0.2814*
78	-0.2776*
79	-0.2776
84	-0.2677
86	-0.2616*
95	-0.2521
101	-0.2521
104	-0.2321*
113	-0.2391*
116	-0.2272
118	-0.2150*
119	-0.2094*
121	-0.2024
123	-0.1887
123	-0.1847
123	-0.1813*
129	-0.1840*
CURVE 6 (cont.)	
143	-0.1777
150	-0.1741
150	-0.1664*
162	-0.1601
184	-0.1372
209	-0.1073
247	-0.0609
264	-0.0438
283	-0.0128
293	0.0000*
294	0.0000*
300	0.0053
300	0.0116*
300	0.0157*
301	0.0188*
305	0.0159
CURVE 7	
34	-0.324
35	-0.324*
77	-0.304
84	-0.292
93	-0.279
111	-0.234*
116	-0.223*
121	-0.218
130	-0.193
138	-0.184
149	-0.169*
157	-0.155
295	0.007*
300	0.009*

*Not shown in figure.

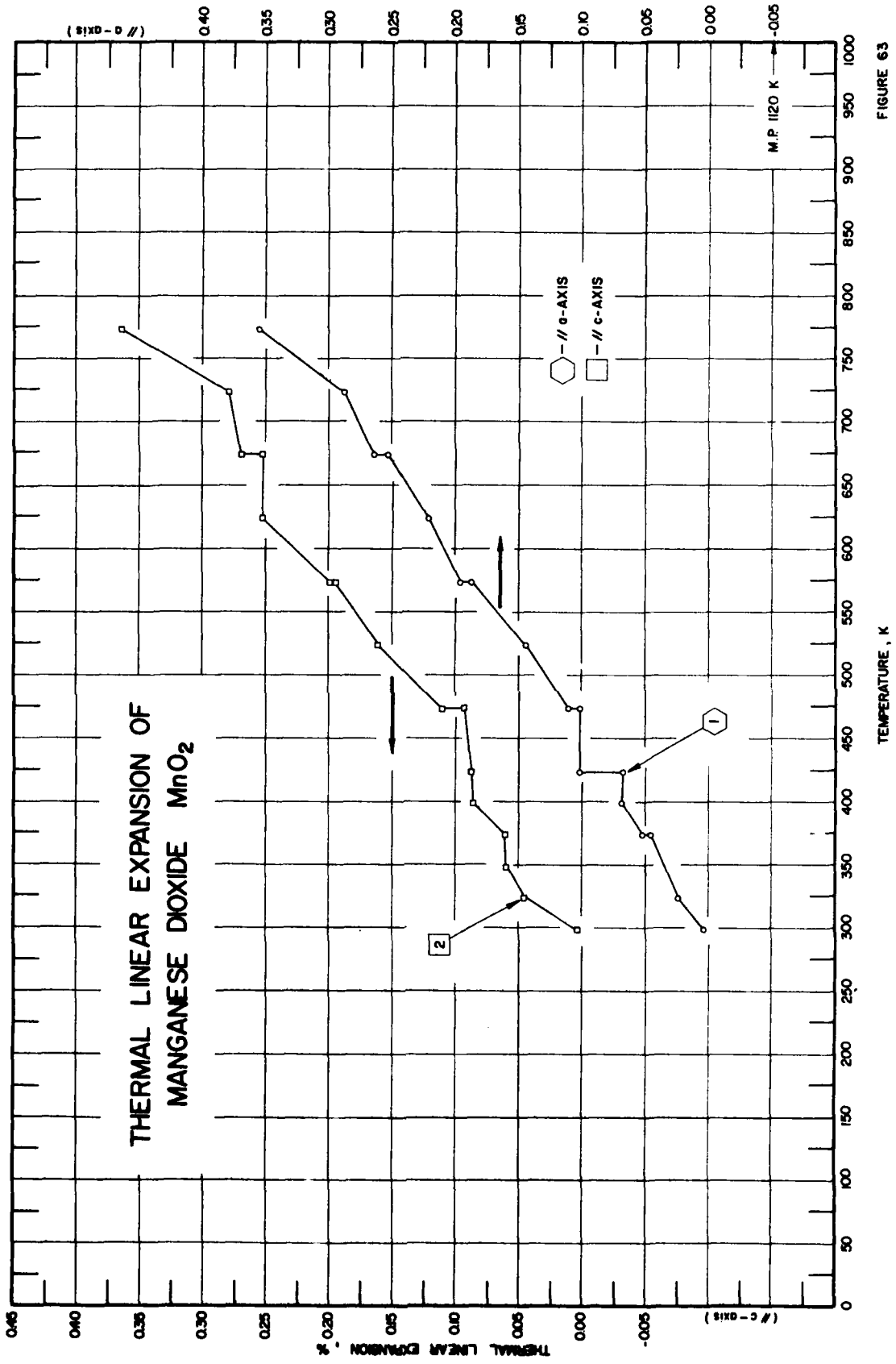

THERMAL LINEAR EXPANSION OF MANGANESE DIOXIDE MnO_2
// a-AXIS
// c-AXIS
M.P. 1120 K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
(// a - AXIS)
(// c - AXIS)
1
2

FIGURE 63

SPECIFICATION TABLE 63. THERMAL LINEAR EXPANSION OF MANGANESE DIOXIDE MnO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	124	Bradt, R.C. and Wiley, J.S.	1962	X	298-773	β-$MnO_{2.00}$	0.04-0.09 H_2O; tetragonal unit cell specimen prepared by thermal decomposition of manganese nitride solution, then ground to pass 200 mesh screen; decomposed to Mn_2O_3 above 773 K; expansion measured with Fe-$K_{\alpha 1}$ radiation along a-axis in air atmosphere; coefficient of thermal linear expansion 6.69×10^{-6} K^{-1} over temperature range of 298-773 K; zero-point correction of 0.003% determined by graphical extrapolation.
2	124	Bradt, R.C. and Wiley, J.S.	1962	X	298-773	β-$MnO_{2.00}$	The above specimen; expansion measured along c-axis; coefficient of thermal linear expansion 6.93×10^{-6} K^{-1} over temperature range of 298-773 K; zero-point correction of 0.003% determined by graphical extrapolation.
3*	635	Riedner, R.J.	1971	X	298,473	β-MnO_2	99.7 pure β-MnO_2 (Pyrolusite) from Fisher Scientific Co.: insoluble in acid 0.018%, chloride (Cl) 0.010%, sulfate (SO_4) 0.038%, alkalies and earths 0.012%; ground powder mixed with 25% Pt from Goldsmith and sprinkled on a glass slide with two-sided tape; $2\theta = 77°$; curve for plane (220); α-spacing reported at 298 K is 1.5577 Å; 1.5576 Å at 293 K determined by graphical extrapolation.
4*	635	Riedner, R.J.	1971	X	298,473	β-MnO_2	Similar to the above specimen except $2\theta = 84°$; curve for plane (002); α-spacing reported at 298 K is 1.4376 Å; 1.4375 Å at 293 K determined by graphical extrapolation.
5*	635	Riedner, R.J.	1971	X	298,473	β-MnO_2	Similar to the above specimen except $2\theta = 88°$; curve for plane (310); α-spacing reported at 298 K is 1.3912 Å; 1.3911 Å at 293 K determined by graphical extrapolation.
6*	635	Riedner, R.J.	1971	X	298,473	β-MnO_2	Similar to the above specimen except $2\theta = 95°$; curve for plane (301); α-spacing reported at 298 K is 1.3061 Å; 1.3060 Å at 293 K determined by graphical extrapolation.
7*	635	Riedner, R.J.	1971	X	298,473	β-MnO_2	Similar to the above specimen except $2\theta = 36°$; curve for plane (110); α-spacing reported at 298 K is 3.1212 Å; 3.1210 Å at 293 K determined by graphical extrapolation.
8*	635	Riedner, R.J.	1971	X	298,473	β-MnO_2	Similar to the above specimen except $2\theta = 47°$; curve for plane (101); α-spacing reported at 298 K is 2.4121 Å; 2.4119 Å at 293 K determined by graphical extrapolation.
9*	635	Riedner, R.J.	1971	X	298,473	β-MnO_2	Similar to the above specimen except $2\theta = 54°$; curve for plane (111); α-spacing reported at 298 K is 2.1165 Å; 2.1164 Å at 293 K determined by graphical extrapolation.
10*	635	Riedner, R.J.	1971	X	298,473	β-MnO_2	Similar to the above specimen except $2\theta = 73°$; curve for plane (211); α-spacing reported at 298 K is 1.6258 Å; 1.6257 Å at 293 K determined by graphical extrapolation.
11*	635	Riedner, R.J.	1971	X	298,473		The thermal linear coefficient data along x-axis determined by using least-squares computer program to the above eight planes.
12*	635	Riedner, R.J.	1971	X	298,473		Similar to the above specimen except along z-axis.

* Not shown in figure.

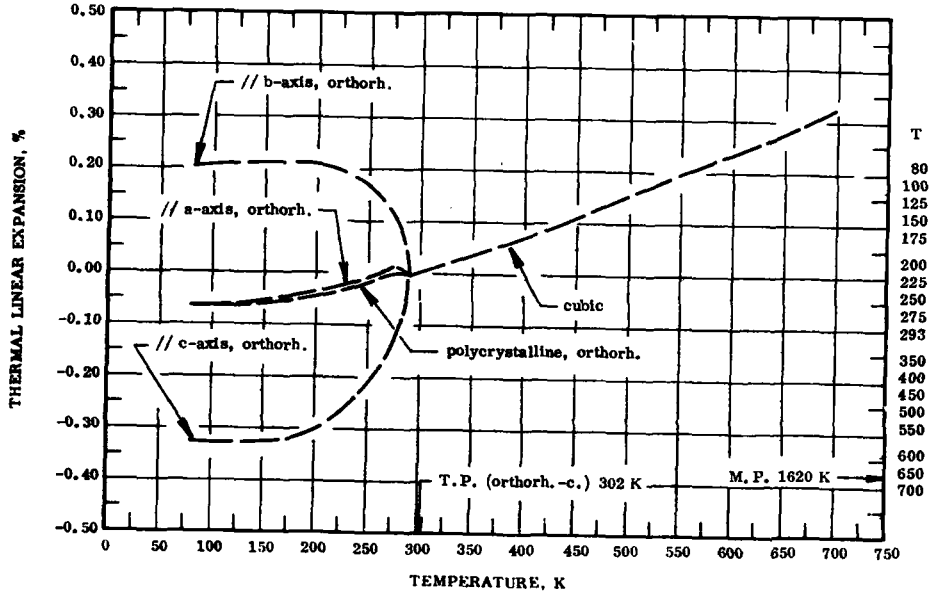
DATA TABLE 63. THERMAL LINEAR EXPANSION OF MANGANESE DIOXIDE MnO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.003
323	0.024
373	0.046
373	0.052
398	0.069
423	0.069
423	0.101
473	0.102
473	0.111
523	0.145
573	0.188
573	0.196
623	0.222
673	0.255
673	0.265
723	0.289
773	0.356*
CURVE 2	
298	0.003
323	0.046
348	0.060
373	0.061
398	0.086
423	0.088
473	0.093
473	0.111
523	0.161
573	0.195
573	0.199
623	0.253
673	0.253
673	0.270
723	0.280
773	0.365
CURVE 3*	
298	0.0064
473	0.1862
CURVE 4*	
298	0.0070
473	0.2226
CURVE 5*	
298	0.0072
473	0.3091
CURVE 6*	
298	0.0077
473	0.1991
CURVE 7*	
298	0.0064
473	0.2499
CURVE 8*	
298	0.0083
473	0.2985
CURVE 9*	
298	0.0047
473	0.2032
CURVE 10*	
298	0.0062
473	0.2153
CURVE 11*	
298	0.006
473	0.236
CURVE 12*	
298	0.006
473	0.234

* Not shown in figure.

FIGURE AND TABLE NO. 64R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF DIMANGANESE TRIOXIDE Mn_2O_3



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

Orthorhombic phase				Cubic phase	
// a-axis	// b-axis	// c-axis	polycrystalline		
$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
-0.065	0.204	-0.328	-0.063		
-0.062	0.205	-0.329	-0.062		
-0.060	0.207	-0.329	-0.061		
-0.053	0.208	-0.329	-0.058		
-0.048	0.209	-0.321	-0.053		
-0.040	0.210	-0.300	-0.043		
-0.028	0.200	-0.267	-0.032		
-0.010	0.172	-0.217	-0.018		
0.018	0.112	-0.135	-0.002		
0.000	0.000	0.000	0.000	0.000	5.8
				0.036	6.8
				0.072	7.5
				0.110	8.0
				0.152	8.4
				0.194	8.5
				0.237	8.6
				0.279	8.6
				0.320	8.7

REMARKS

The provisional values for the axial thermal expansion of the sample of orthorhombic structure are based on the data for pure sample. The values for the polycrystalline sample are calculated from the axial values at temperatures below 302 K and are based on the data reported in curve 1 at temperatures above 302 K. These values are considered accurate to within ±10%. The values for cubic phase are represented approximately by the following equation:

Cubic phase: $\Delta L/L_0 = -0.055 - 3.019 \times 10^{-4} T + 2.012 \times 10^{-6} T^2 - 1.164 \times 10^{-9} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

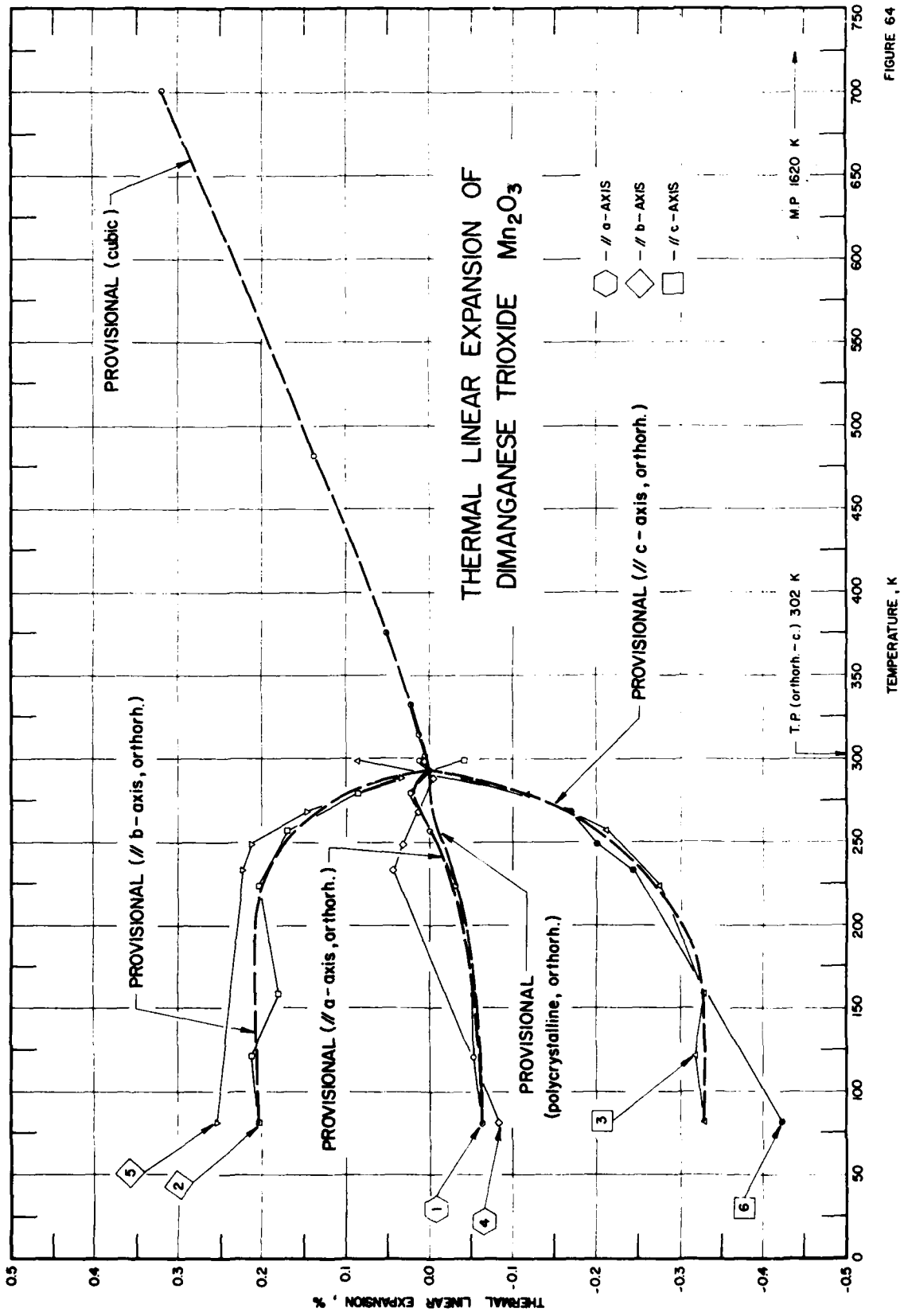

THERMAL LINEAR EXPANSION OF
DIMANGANESE TRIOXIDE Mn_2O_3
PROVISIONAL (cubic)
PROVISIONAL (// b-axis, orthorh.)
PROVISIONAL (// a-axis, orthorh.)
PROVISIONAL (// c-axis, orthorh.)
PROVISIONAL
(polycrystalline, orthorh.)
// a-AXIS
// b-AXIS
// c-AXIS
M.P 1620 K
T.P (orthorh.-c.) 302 K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
1
2
3
4
5
6

FIGURE 64

SPECIFICATION TABLE 64. THERMAL LINEAR EXPANSION OF DIMANGANESE TRIOXIDE Mn_2O_3

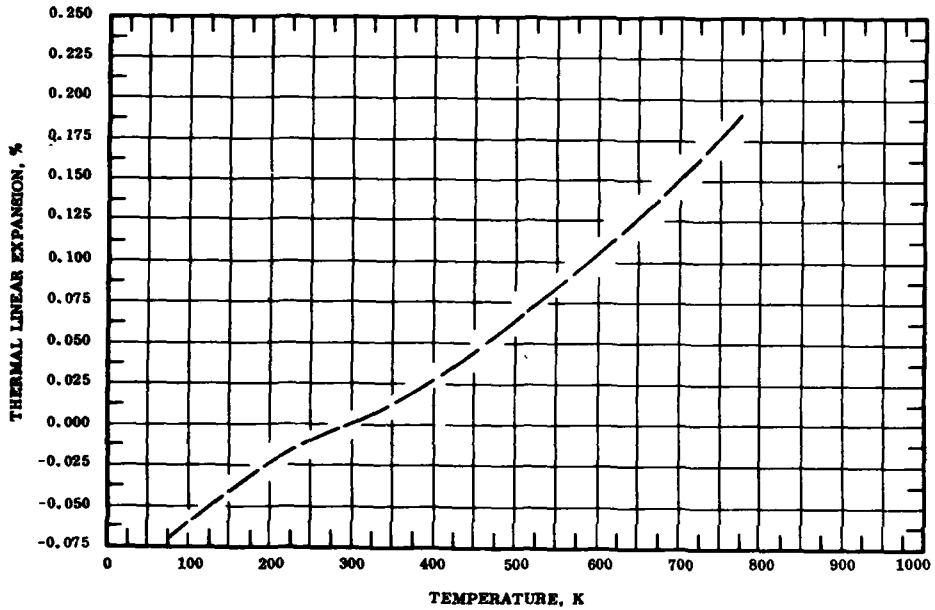
Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	126	Geller, S. and Espinosa, G. P.	1970	X	81-702		Powder specimen; prepared by grinding single crystal of pure Mn_2O_3; transition temperature at 302 K from orthorhombic to cubic phase; expansion measured with CrKα radiation along a-axis; lattice constant reported at 81 K is 9.407 Å; 9.413 Å at 293 K determined by graphical interpolation.
2	126	Geller, S. and Espinosa, G. P.	1970	X	81-298		The above specimen; expansion measured along b-axis of orthorhombic phase; lattice constant reported at 81 K is 9.447 Å; 9.428 Å at 293 K determined by graphical interpolation.
3	126	Geller, S. and Espinosa, G. P.	1970	X	81-298		The above specimen; expansion measured along c-axis of orthorhombic phase; lattice constant reported at 81 K is 9.366 Å; 9.397 Å at 293 K determined by graphical interpolation.
4	126	Geller, S. and Espinosa, G. P.	1970	X	81-298	$(Mn_{1-x}Sc_x)_2O_3$ x = 0.007	Single crystal specimen; prepared by flux technique; expansion measured along a-axis of orthorhombic phase; lattice constant reported at 81 K is 9.406 Å; 9.414 Å at 293 K determined by graphical interpolation.
5	126	Geller, S. and Espinosa, G. P.	1970	X	81-288	$(Mn_{1-x}Sc_x)_2O_3$ x = 0.007	The above specimen; expansion measured along b-axis of orthorhombic phase; lattice constant reported at 81 K is 9.447 Å; 9.423 Å at 293 K determined by graphical extrapolation.
6	126	Geller, S. and Espinosa, G. P.	1970	X	81-288	$(Mn_{1-x}Sc_x)_2O_3$ x = 0.007	The above specimen; expansion measured along c-axis of orthorhombic phase; lattice constant reported at 81 K is 9.366 Å; 9.406 Å at 293 K determined by graphical extrapolation.

DATA TABLE 64. THERMAL LINEAR EXPANSION OF DIMANGANESE TRIOXIDE Mn_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
81	-0.064
121	-0.053
158	-0.053
223	-0.032
257	0.000
279	0.021
293	0.000
298	0.011
302	0.005
314	0.011
332	0.021
375	0.053
482	0.138
702	0.319
CURVE 2	
81	0.202
121	0.212
158	0.180
223	0.202
257	0.170
279	0.085
298	-0.042
CURVE 3	
81	-0.330
121	-0.319
158	-0.330
223	-0.277
257	-0.213
279	-0.117
298	0.085
CURVE 4	
81	-0.0849
233	0.0424
248	0.0318
268	0.0212
288	-0.0106
298	0.0106
CURVE 5	
81	0.2546
233	0.2228
248	0.2122
268	0.1485
288	0.0318
CURVE 6	
81	-0.4252
233	-0.2445
248	-0.2019
268	-0.1701
288	-0.0425

FIGURE AND TABLE NO. 65R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF DIMOLYBDENUM TRIOXIDE Mo_2O_3



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
75	-0.068	3.7
100	-0.058	3.7
125	-0.049	3.6
150	-0.040	3.6
175	-0.031	3.4
200	-0.023	3.2
225	-0.015	3.0
250	-0.009	2.5
275	-0.003	2.0
293	0.000	1.1
325	0.006	2.3
350	0.012	2.7
375	0.019	3.1
400	0.027	3.4
425	0.035	3.5
450	0.044	3.7
475	0.053	3.9
500	0.063	4.1
550	0.085	4.4
600	0.107	4.6
650	0.131	4.8
700	0.155	4.9
750	0.180	4.9
775	0.192	4.9

REMARKS

The provisional values are based on the data for powdered samples. Expansion anomaly occurs as temperature falling to 373 K or lower, the coefficient of thermal expansion falls considerably to the minimum values at 293 K, and then increases at temperatures below 293 K. These values are considered accurate to within ± 7% and are represented approximately by the following equations:

$$\Delta L/L_0 = -0.094 + 3.169 \times 10^{-4}\ T + 5.540 \times 10^{-7}\ T^2 - 1.844 \times 10^{-9}\ T^3 \quad (75\text{-}293\ K)$$

$$\Delta L/L_0 = 0.016 - 3.491 \times 10^{-4}\ T + 1.152 \times 10^{-6}\ T^2 - 5.266 \times 10^{-10}\ T^3 \quad (293\text{-}775\ K)$$

The tabulated values for the coefficient of thermal expansion are derived from the experimental data and are considered accurate to about ± 10%.

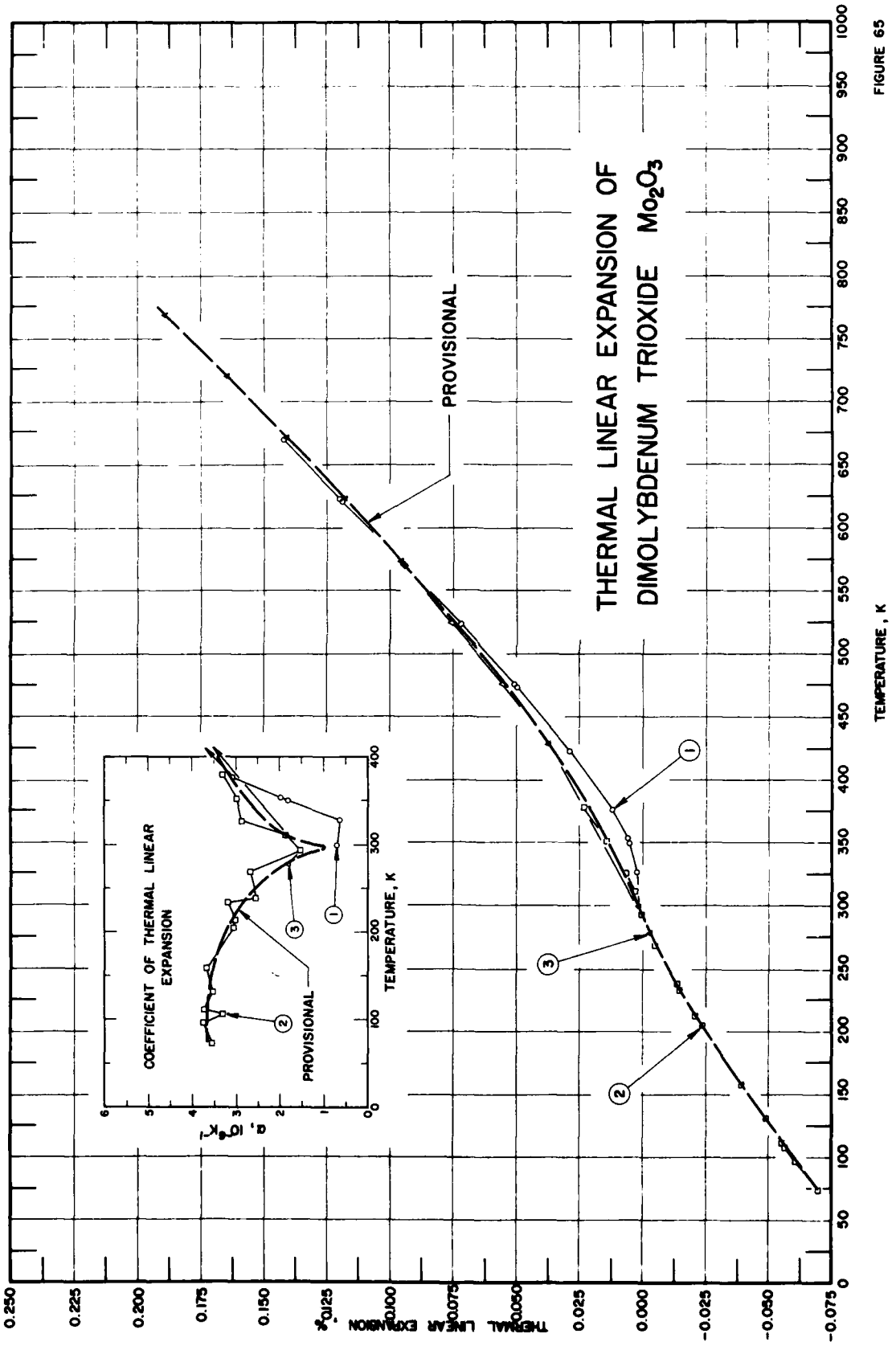

THERMAL LINEAR EXPANSION OF
DIMOLYBDENUM TRIOXIDE Mo_2O_3
PROVISIONAL
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α, $10^{-6}K^{-1}$
PROVISIONAL
TEMPERATURE, K
0.250
0.225
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
-0.025
-0.050
-0.075
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1
2
3

FIGURE 65

SPECIFICATION TABLE 65. THERMAL LINEAR EXPANSION OF DIMOLYBDENUM TRIOXIDE Mo_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	127	Mironov, O.S., Shmakov, A.D., Batenina, O.I., Novikova, K.Z., Danielyan, T.A., and Tyukalov, Yu.M.	1966	L	300-669		Specimen prepared by reduction of MoO_3; powder made into compacts 10 x 10 mm cross section and sintered in argon atmosphere at 1273 K for 6 hr; expansion measured using Parnov capacitance dilatometer.
2	127	Mironov, O.S., et al.	1966	L	379-73		The above specimen; expansion measured with decreasing temperature.
3	127	Mironov, O.S., et al.	1966	L	278-768		Similar to the above specimen; expansion measured using Chevenard dilatometer.

DATA TABLE 65. THERMAL LINEAR EXPANSION OF DIMOLYBDENUM TRIOXIDE Mo_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1‡		CURVE 2‡		CURVE 2 (cont.)‡		CURVE 3 (cont.)‡	
300	0.001	379	0.023	97	-0.061	768	0.188
327	0.002	352	0.014	73	-0.070		
351	0.005	327	0.007				
353	0.006	311	0.003	CURVE 3‡			
377	0.012	293	0.000				
423	0.028	269	-0.005	278	-0.003		
474	0.049	239	-0.013	293	0.000*		
476	0.050	234	-0.014	429	0.037		
524	0.072	213	-0.021	476	0.055		
570	0.093	205	-0.023	525	0.075		
572	0.094	158	-0.039	574	0.096		
620	0.118	131	-0.049	622	0.118		
622	0.119	112	-0.056	671	0.141		
669	0.142	107	-0.057	720	0.164		

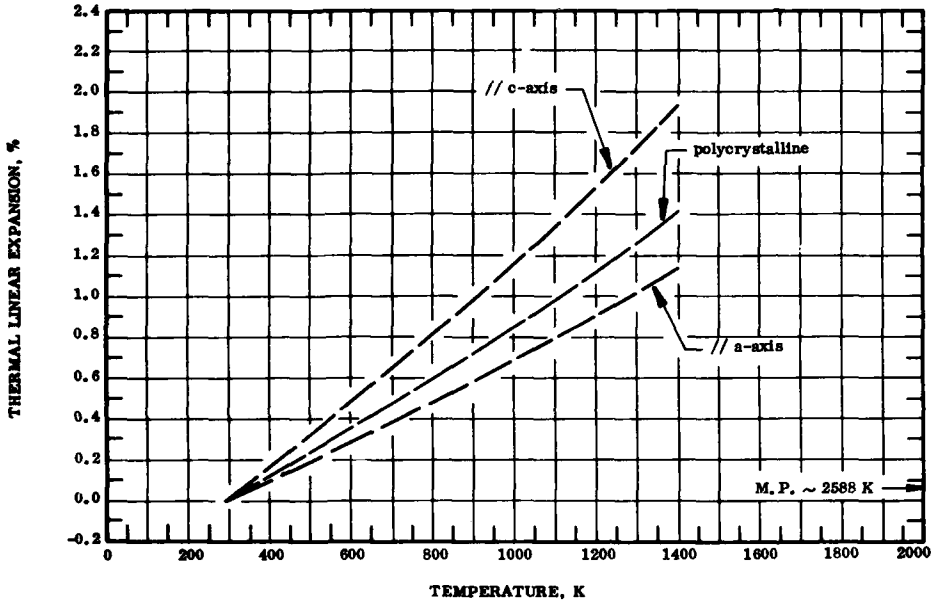
DATA TABLE 65. COEFFICIENT OF THERMAL LINEAR EXPANSION OF DIMOLYBDENUM TRIOXIDE Mo_2O_3

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α
CURVE 1‡		CURVE 2*,‡		CURVE 3‡	
300	0.70	73	3.55	278	1.81
327	0.62	97	3.75	293	1.53*
351	1.82	107	3.30	429	3.85*
353	1.97	112	3.74	476	4.00*
377	3.08	131	3.51	525	4.15*
423	3.98*	158	3.68	574	4.50*
474	4.47*	205	3.05	622	4.71*
476	4.35*	213	3.02	671	4.57*
524	4.57*	234	3.18	720	4.79*
570	4.78*	239	2.54	768	5.35*
572	4.90*	269	2.66		
620	5.01*	293	1.53		
622	4.87*	311	1.88		
669	5.03*	327	2.86		
		352	2.98		
		379	3.30		

* Not shown in figure.
‡ Author's data for coefficient of expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 66R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF NEODYMIUM OXIDE Nd_2O_3



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	11.0
400	0.169	0.098	0.122	11.5
500	0.328	0.195	0.240	11.6
600	0.487	0.290	0.354	11.7
700	0.648	0.387	0.472	11.9
800	0.813	0.484	0.593	12.2
900	0.982	0.584	0.718	12.6
1000	1.157	0.687	0.845	13.0
1100	1.338	0.792	0.977	13.5
1200	1.528	0.902	1.118	14.0
1300	1.726	1.015	1.257	14.6
1400	1.935	1.133	1.406	15.3

REMARKS

The provisional values for the axial thermal expansion are based on the data for pure samples (curves 4 and 5 for // c-axis; curves 2, 3, and 6 for // a-axis). The values for polycrystalline sample are calculated from the axial values. These values are considered accurate to within ± 7% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -0.476 + 1.678 \times 10^{-3} T - 2.370 \times 10^{-7} T^2 + 1.920 \times 10^{-10} T^3$

// a-axis: $\Delta L/L_0 = -0.281 + 9.791 \times 10^{-4} T - 9.493 \times 10^{-8} T^2 + 8.341 \times 10^{-11} T^3$

polycrystalline: $\Delta L/L_0 = -0.338 + 1.171 \times 10^{-3} T + 9.356 \times 10^{-8} T^2 + 1.048 \times 10^{-10} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ± 10%.

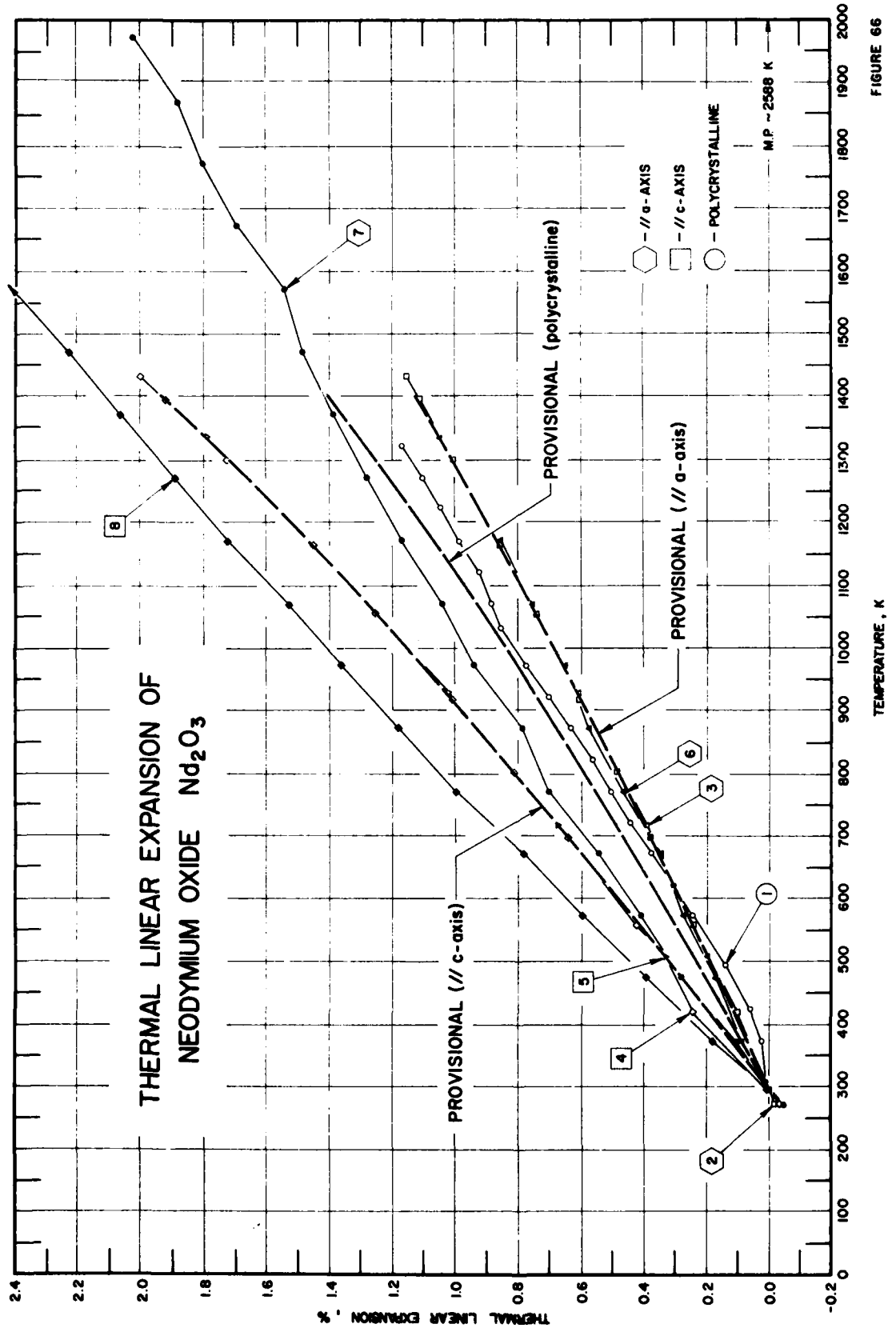

THERMAL LINEAR EXPANSION OF
NEODYMIUM OXIDE Nd_2O_3
PROVISIONAL (polycrystalline)
PROVISIONAL (// a-axis)
PROVISIONAL (// c-axis)
// a-AXIS
// c-AXIS
POLYCRYSTALLINE
M.P. ~2568 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1
2
3
4
5
6
7
8

FIGURE 66

SPECIFICATION TABLE 66. THERMAL LINEAR EXPANSION OF NEODYMIUM OXIDE Nd_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	125	Mistler, R.E., Ploetz, G.L., and Smith, Y.A.	1963	L	308-1323	Nd_2O_3-629.9	99.9 pure; specimen obtained from Lindsey Chemical Div. of American Potash and Chemical Corp., West Chicago, Illinois; dry-pressed at pressure of 20 000 psi in double acting steel die into pellet 0.5 in. diameter, 2 in. long; pelle sintered at 1723 K for 1 hr in oxidizing atmosphere, cooled in furnace to 473 K and then cooled in vacuum desiccator to room temperature; zero-point correction of 0.016% determined by graphical extrapolation.
2	68	Stecura, S. and Campbell, W.J.	1961	X	273-1431		99.9 pure; specimen obtained from Lindsey Chemical Co.; sintered at 1373 K for 24 hr, packed into alumina holder, sintered again at 1373 K for 12 hr; cooled to 1023 K and stored in vacuum; expansion measured along a-axis; unit cell parameter reported at 273.2 K is 3.8287 Å; zero-point correction of -0.014% determined by graphical interpolation.
3	68	Stecura, S. and Campbell, W.J.	1961	X	1336-508		The above specimen; expansion measured along a-axis with decreasing temperature; zero-point correction of -0.014% determined by graphical extrapolation.
4	68	Stecura, S. and Campbell, W.J.	1961	X	273-1431		The above specimen; expansion measured along c-axis with increasing temperature; unit cell parameter reported at 273.2 K is 5.9950 Å; zero-point correction of -0.030% determined by graphical interpolation.
5	68	Stecura, S. and Campbell, W.J.	1961	X	1336-508		The above specimen; expansion measured along c-axis with decreasing temperature; zero-point correction of -0.030% determined by graphical extrapolation.
6	590	Rudenko, V.S. and Boganov, A.G.	1970	X	273-1173		Transition temperature from cubic structure to hexagonal structure at 1013 K with volume construction -9.2%; lattice parameter of cubic structure is 11.079 Å reported at 273 K; 11.081 Å at 293 K determined by graphical interpolation.
7	590	Rudenko, V.S. and Boganov, A.G.	1970	X	273-2273		Similar to the above specimen; lattice parameter along a-axis of hexagonal structure is 3.825 Å reported at 273 K; 3.827 Å at 293 K determined by graphical interpolation.
8	590	Rudenko, V.S. and Boganov, A.G.	1970	X	273-2273		The above specimen; lattice parameter along c-axis of hexagonal structure is 6.007 Å reported at 273 K; 6.009 Å at 293 K determined by graphical interpolation.

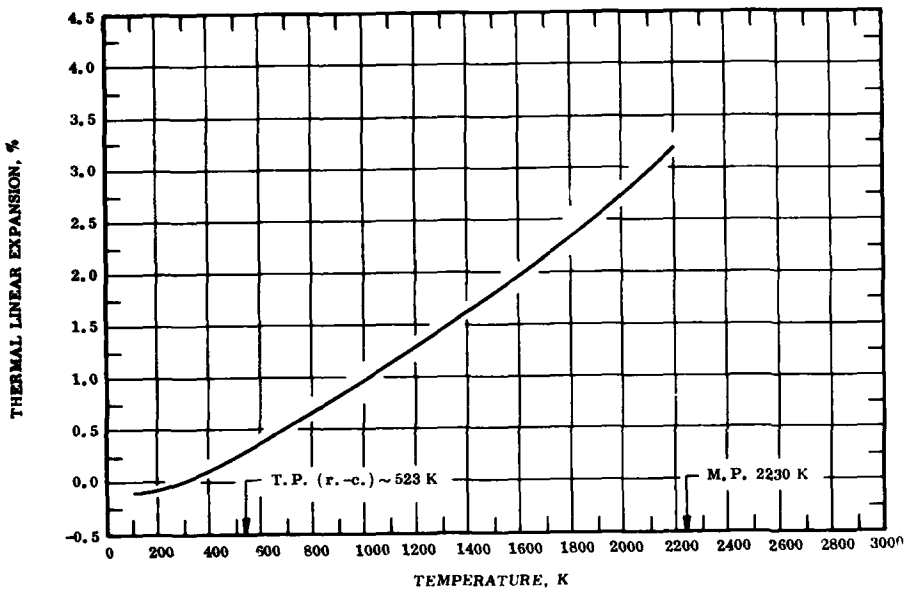
DATA TABLE 66. THERMAL LINEAR EXPANSION OF NEODYMIUM OXIDE Nd_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
308	0.016
373	0.026
423	0.065
493	0.144
573	0.252
623	0.314
673	0.380
723	0.447
773	0.509
823	0.571
873	0.639
923	0.703
973	0.777
1035	0.855
1073	0.885
1123	0.925
1173	0.988
1223	1.051
1273	1.114
1323	1.175
CURVE 2	
273	-0.014
296	0.002
419	0.104
558	0.245
697	0.380
801	0.488
919	0.608
1056	0.747
1167	0.858
1300	1.010
1395	1.117
1431	1.164
CURVE 3	
1336	1.054
929	0.608
719	0.395
508	0.200
CURVE 4	
273	-0.030
296	0.004
419	0.250
558	0.424
697	0.641
801	0.811
919	1.011
1056	1.246
1167	1.453
1300	1.730
1395	1.915
1395	1.915
1431	1.997
CURVE 5	
1336	1.793
929	1.021
719	0.676
508	0.339
CURVE 6	
273	-0.018*
373	0.090
473	0.180
573	0.280
673	0.352
773	0.469
873	0.578
973	0.659
1073	0.758
1173	0.857
CURVE 7	
273	-0.052
373	0.105
473	0.287
573	0.418
673	0.549
773	0.705
873	0.784
973	0.941
1073	1.045
1173	1.176
1273	1.280
1373	1.385
1473	1.489
1573	1.542
1673	1.698
1773	1.803
1873	1.881
1973	2.012
2073	2.116*
2173	2.195*
2273	2.247*
CURVE 8	
273	-0.033*
373	0.183
473	0.399
573	0.599
673	0.782
773	0.998
873	1.182
973	1.365
1073	1.531
1173	1.731
1273	1.897
1373	2.064
1473	2.230
1573	2.413*
1673	2.546*
1773	2.729*
1873	2.879*
1973	3.079*
2073	3.228*
2173	3.362*
2273	3.495*

* Not shown in figure.

FIGURE AND TABLE NO. 67R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF NICKEL OXIDE NiO



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
100	-0.100	4.4
200	-0.060	6.9
293	0.000	10.2
400	0.134	13.0
500	0.262	14.0
523†	0.295	15.0
600	0.400	13.5
700	0.530	13.5
800	0.670	13.5
900	0.815	13.6
1000	0.960	13.6
1100	1.110	13.7
1200	1.271	13.7
1300	1.435	14.8
1400	1.605	15.8
1500	1.781	16.5
1600	1.965	17.2
1700	2.153	17.9
1800	2.350	18.7
1900	2.555	19.4
2000	2.770	20.2
2100	2.990	21.1
2200	3.216	22.0

† Transition temperature from rhombohedral to cubic structure.

REMARKS

The recommended values are considered accurate to within ±5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.353 + 1.177 \times 10^{-3} T + 8.107 \times 10^{-6} T^2 + 5.523 \times 10^{-11} T^3 \qquad (293\text{-}2200\ K)$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±7%.

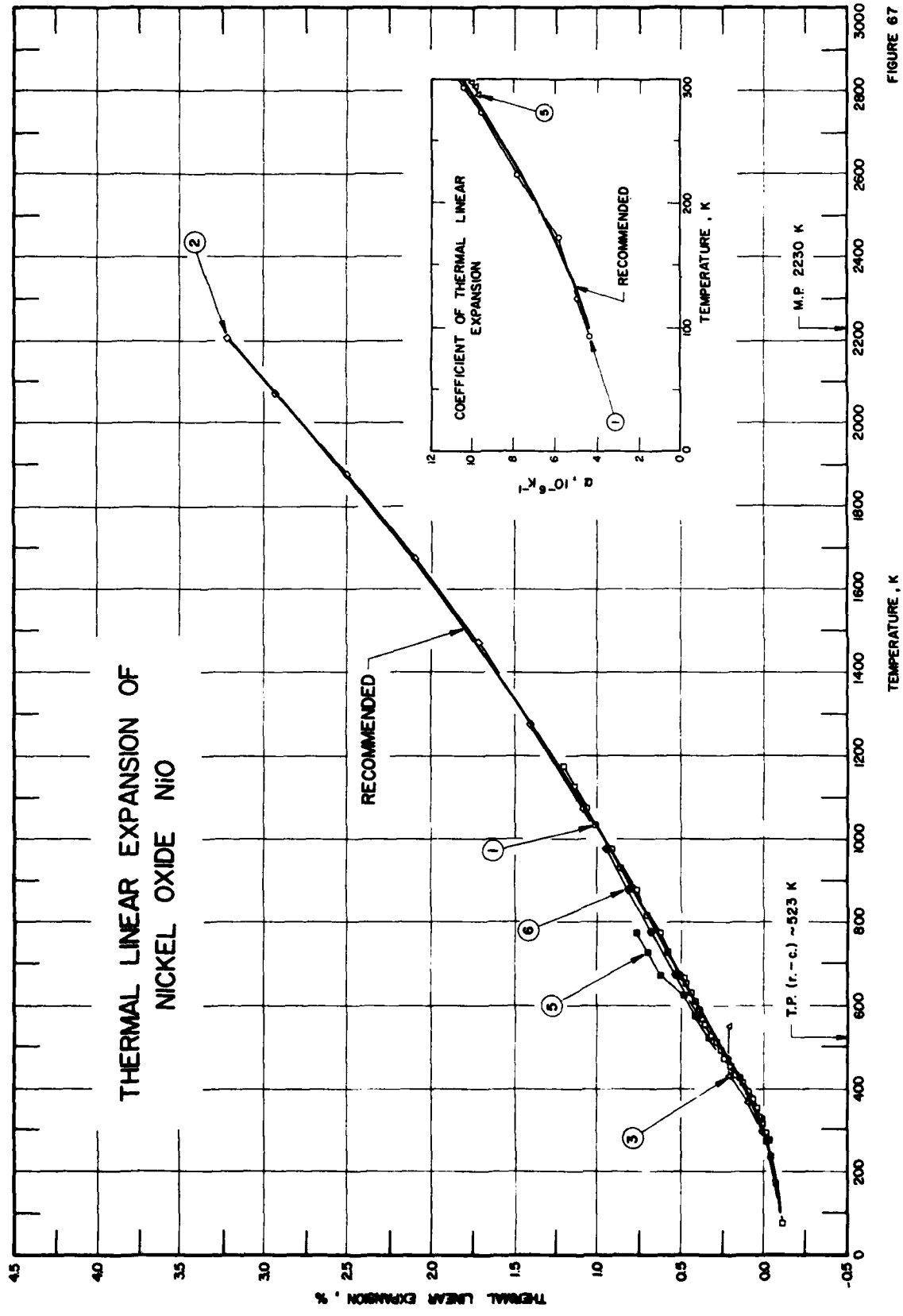

THERMAL LINEAR EXPANSION OF
NICKEL OXIDE NiO
RECOMMENDED
M.P 2230 K
T.P. (r.-c.) ~523 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
α , 10⁻⁶ K⁻¹
TEMPERATURE , K

FIGURE 67

SPECIFICATION TABLE 67. THERMAL LINEAR EXPANSION OF NICKEL OXIDE NiO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	132	Melik-Davtyan, R. L., Shavartsenov, N. F., and Shelykh, A. I.	1966		73-1179		0.59 Li; specimen 4 mm diameter, 35-40 mm long; prepared by drying pure nickel nitrate at 393 to 423 K, roasted at 1573 K for 2 hr, pressed to shape at 3800 kg cm^{-2} and roasted in furnace at 1273 K for 3 hr, final roasting at 1473 K for 5.5 hr; zero-point correction of -0.128% determined by graphical interpolation; coefficient of thermal linear expansion also tabulated.
2	90, 131	Leipold, M. H. and Nielsen, T.	1964	L	298-2203		Polycrystalline specimen, 0.75 in diameter, 2 in. long; grain size 1.5 μ; prepared from reagent-grade nickel sulfate; calcined at 1173 K for 20 hr in air, hot-pressed at 10 000 psi and 1273 K for 90 min in oxygen atmosphere, welded two 2 in. blocks together by hot pressing as before; heated to 2073 K for 1 hr in 95 O_2-5 N_2 atmosphere; density 6.44 g cm^{-3} as fabricated, 6.57 g cm^{-3} after 2073 K heat treatment, 6.56 g cm^{-3} after 1st test to 2073 K; expansion measured in 95 O_2-5 N_2 atmosphere; average value of two tests.
3	134	Gillam, E. and Holden, J. P.	1963	X	293-548	Rhombohedral structure	Specimen made from nickel particles $\approx$1 μ in size which were oxidized in air at 973 K; welted with aluminum nitrate solution and dried at 373 K; mixture decomposed to mixed oxides and ignited at 1573 K for 1 hr in air, then cooled in air; ignition at 1573 K produced rhombohedral distortion at room temperature; as temperatures approached Néel point, distortion decreased and cubic structure seemed to be established at 433 K; expansion measured using Co radiation along a-axis; lattice parameter reported at 293.2 K is 2.9534 Å.
4*	134	Gillam, E. and Holden, J. P.	1963	X	432-1573	Cubic structure	Similar to the above specimen except cubic structure; only data on the lattice parameter are tabulated.
5	135	Trombe, F. and Foex, M.	1953	L	273-773		Expansion measured in hydrogen atmosphere below room temperature, in argon atmosphere above room temperature; zero-point correction of -0.020%; coefficient of thermal linear expansion also tabulated.
6	128	Wisely, H. R.	1962	L	293-1073		Bar specimen 0.250 x 0.375 x 2 in.; prepared under pressure of 26 000 psi, sintered for 16 hr in air atmosphere; phase inversion at 473 K; reported error $\pm$1%.

* Not shown in figure.

DATA TABLE 67. THERMAL LINEAR EXPANSION OF NICKEL OXIDE NiO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
73	-0.128
170	-0.067
234	-0.039
270	-0.007
290	-0.002
311	0.014
330	0.035
349	0.054
374	0.084
390	0.102
413	0.135
430	0.176
453	0.208
473	0.244
494	0.264
510	0.295
529	0.321
551	0.355
568	0.359
589	0.387
CURVE 1 (cont.)	
608	0.416
632	0.443
652	0.472
665	0.487
727	0.572
771	0.637
818	0.712
873	0.777
927	0.859
974	0.921
1035	1.012
1076	1.070
1129	1.142
1179	1.208
CURVE 2	
298	0.006
473	0.236
673	0.505
CURVE 2 (cont.)	
873	0.783
1073	1.08
1273	1.39
1473	1.73
1673	2.10
1873	2.51
2073	2.94
2203	3.23
CURVE 3	
293	0.0000*
363	0.1117
433	0.2234
548	0.2234

T	a (Å)
CURVE 4*	
432	4.1865 cub.
532	4.1923
549	4.1945
914	4.2156
1103	4.2258
1272	4.2360
1573	4.2532

T	$\Delta L/L_0$
CURVE 5	
273	-0.020
293	0.000*
323	0.030
373	0.091
423	0.155
473	0.246*
523	0.336
573	0.415
CURVE 5 (cont.)	
623	0.489
673	0.561
723	0.630
773	0.700
CURVE 6	
293	0.00*
373	0.08*
473	0.25*
573	0.40
673	0.54
773	0.68
873	0.81
973	0.95
1073	1.09*

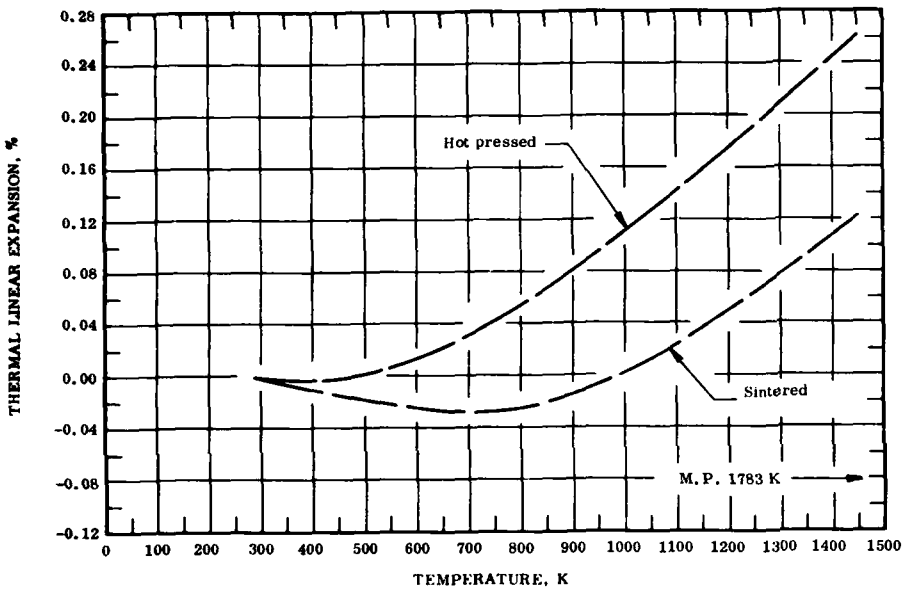
DATA TABLE 67. COEFFICIENT OF THERMAL LINEAR EXPANSION OF NICKEL OXIDE NiO

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1	
93	4.40
123	5.00
173	5.92
223	7.88
273	9.67
293	10.40
323	11.34*
373	12.71*
423	13.32*
473	13.38*
523	14.96*
573	13.68*
623	13.45*
673	13.45*
723	13.45*
773	13.45*
CURVE 1 (cont.)	
823	13.45*
873	13.45*
923	13.45*
973	13.51*
1023	13.52*
1073	13.60*
1123	13.60*
1173	13.60*
1215	13.62*
CURVE 5	
287	10.00
293	10.19
298	10.42
323	11.11*
348	11.92*
373	12.67*
398	13.67*
423	14.56*
448	15.67*
473	16.86*
498	18.44*
523	23.03*
537	16.12*
548	15.33*
573	14.63*
598	14.35*
CURVE 5 (cont.)	
623	14.19*
648	14.05*
673	13.93*
698	13.88*
723	13.83*
748	13.79*
773	13.79*

*Not shown in figure.

FIGURE AND TABLE NO. 68R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF DINIOBIUM PENTAOXIDE Nb_2O_5



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Sintered		Hot-pressed	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	-2.0	0.000	-0.7
350	-0.005	-1.6	-0.003	-0.3
400	-0.012	-1.3	-0.003	0.1
450	-0.018	-1.1	-0.002	0.4
500	-0.022	-0.8	0.001	0.8
600	-0.028	-0.2	0.014	1.5
700	-0.028	0.3	0.031	2.0
800	-0.024	0.8	0.054	2.5
900	-0.013	1.3	0.080	2.8
1000	0.003	1.8	0.110	3.1
1100	0.023	2.2	0.142	3.1
1200	0.047	2.6	0.175	3.4
1300	0.076	3.1	0.210	3.5
1400	0.108	3.5	0.245	3.5
1450	0.124	3.7	0.262	3.6

REMARKS

The provisional values for the sintered sample are based on the data reported in curves 1, 8, 11 and 32. A hysteresis due to heating and cooling cycle of sintered samples is observed (curves 23 to 33). The provisional values for the hot-pressed sample are based on the data reported in curves 2 to 4 and 34 to 37. These values are considered accurate to within ± 10% for sintered sample and ± 20% for hot-pressed sample and are represented approximated by the following equations:

Sintered: $\Delta L/L_0 = 0.089 - 3.754 \times 10^{-4}\ T + 3.189 \times 10^{-7}\ T^2 - 2.894 \times 10^{-11}\ T^3$

Hot-Pressed: $\Delta L/L_0 = 0.061 - 3.566 \times 10^{-4}\ T + 5.486 \times 10^{-7}\ T^2 - 1.429 \times 10^{-10}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 10% for sintered sample and ± 20% for hot-pressed sample.

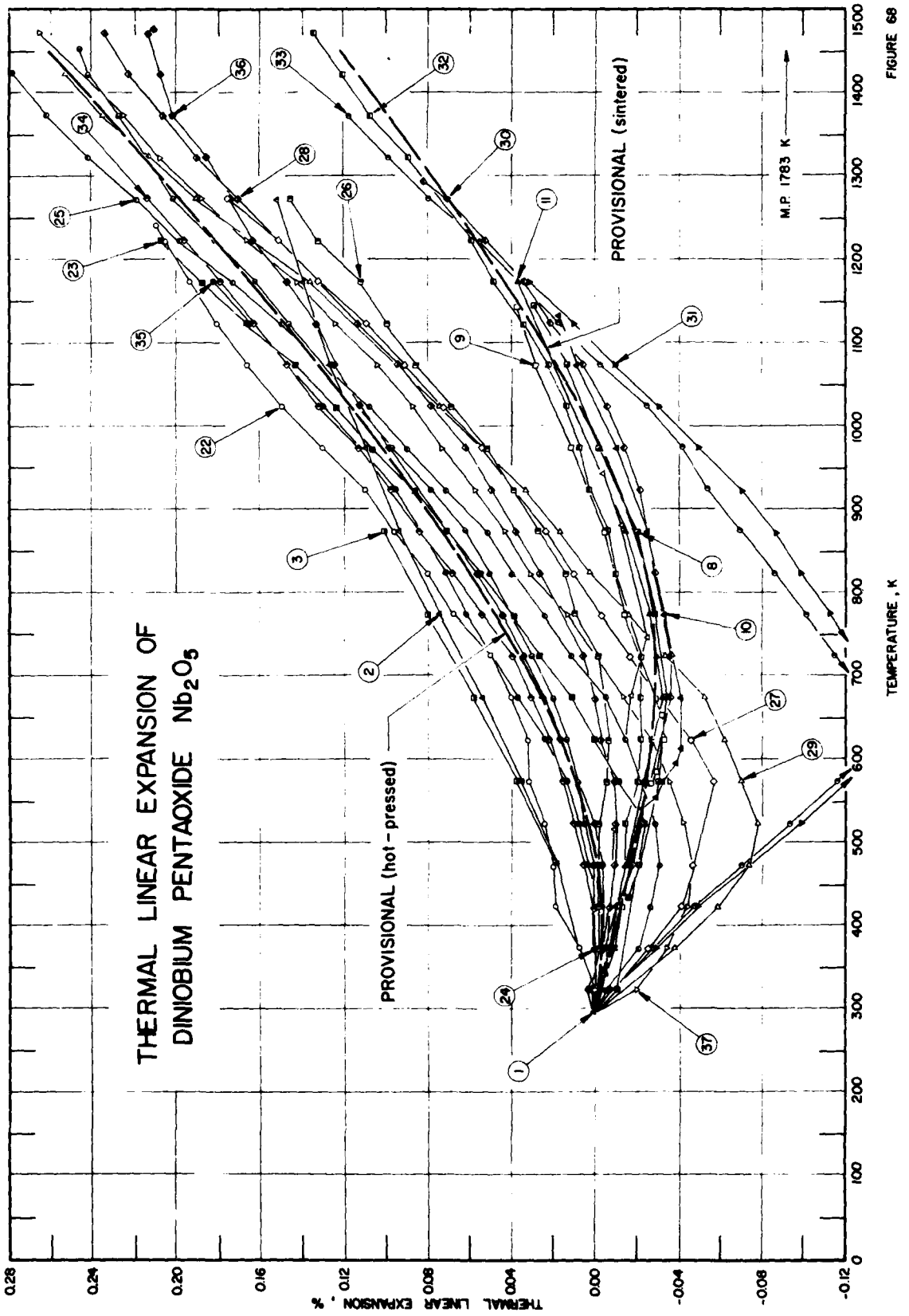

THERMAL LINEAR EXPANSION OF
DINIOBIUM PENTAOXIDE Nb_2O_5
PROVISIONAL (hot-pressed)
PROVISIONAL (sintered)
M.P. 1783 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0.00
-0.04
-0.08
-0.12
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 68

SPECIFICATION TABLE 68. THERMAL LINEAR EXPANSION OF DINIOBIUM PENTAOXIDE Nb_2O_5

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	133	Durbin, E.A., Wagner, H.E., and Harman, L.G.	1952	I	298-944		99.6 Nb_2O_5, most impurity Ta_2O_5; prepared by oxidation of purified Nb metal in fused silica container; sintered in air atmosphere at 1673 to 1753 K.
2	136	Douglas, D.L.	1962	L	293-1273		99.96 pure, stoichiometric specimen; 2 x 2 x 40 mm; prepared by hot-pressing 1.3 μ diameter powder in boron nitride-coated graphite dies in vacuum of 1 μ at 1573 K and 3000 psi for 30 min; density 4.55 g cm^{-3}; expansion measurements at equilibrium condition which held at constant temperature until movement ceased.
3	136	Douglas, D.L.	1962	L	293-873		Similar to the above specimen; expansion measured at heating rate 2.7 C per min.
4*	136	Douglas, D.L.	1962	L	873-293		The above specimen; expansion measured with decreasing temperature at cooling rate 2.7 C per min.
5*	136	Douglas, D.L.	1962	L	293-773	$Nb_2O_{4.978}$	Similar to the above specimen except non-stoichiometric; heating rate 10 C per min.
6*	136	Douglas, D.L.	1962	L	773-293	$Nb_2O_{4.978}$	The above specimen; expansion measured with decreasing temperature at cooling rate 10 C per min.
7*	19	Durbin, E.A. and Harman, C.G.	1952	I	527-1144		99.9 pure; powder specimen of -200 mesh; obtained from A. D. Mackay, Inc.; sintered at 1588 K for 2 hr and cooled in furnace.
8	19	Durbin, E.A. and Harman, C.G.	1952	I	434-1148		Similar to the above specimen except sintered at 1643 K for 2 hr and cooled in furnace.
9	19	Durbin, E.A. and Harman, C.G.	1952	I	571-1141		Similar to the above specimen except sintered at 1588 K for 2 hr and air quenched.
10	19	Durbin, E.A. and Harman, C.G.	1952	I	298-1132		Similar to the above specimen except sintered at 1643 K for 2 hr and air quenched.
11	19	Durbin, E.A. and Harman, E.G.	1952	I	348-1173		Similar to the above specimen except sintered at 1643 K for 2 hr, cooled in furnace, refired at 1473 K for 100 hr and cooled in furnace.
12*	333	Brown, J.J., Jr.	1964	L	293-1235	β-Nb_2O_5	Bar specimen, approximately 10 x 1 x 1 cm; heated at 125 C per hr in Nichrome-wound vertical tube furnace; data from smoothed curve.
13*	637	Kidwell, G.D., Richardson, J.H., and Wolten, G.M.	1971	X	293-1663	α-Nb_2O_5	99.9 pure Nb_2O_5, measurements made after annealing a specimen of αNb_2O_5 thoroughly at a high temperature, for the reflections 020(020), $\bar{4}05(\bar{1}05)$, and 402($\bar{6}02$); expansion normal to plane (010).
14*	637	Kidwell, G.D., et al.	1971	X	293-1663	α-Nb_2O_5	Similar to the above specimen; expansion normal to plane ($\bar{4}05$).
15*	637	Kidwell, G.D., et al.	1971	X	293-1663	α-Nb_2O_5	Similar to the above specimen; expansion normal to plane (201).
16*	639	Dwivedi, G.L. and Subbarao, E.C.	1973	X	293,1073	α-Nb_2O_5	99.5 pure αNb_2O_5 with impurities 0.05 Sn, 0.01 Fe; sample heated at 1473 K for 6 hr to convert to stable α-form; expansion measured along a-axis; lattice parameter reported at 293 K is 21.1857 Å.
17*	639	Dwivedi, G.L. and Subbarao, E.C.	1973	X	293,1073	α-Nb_2O_5	The above specimen; expansion measured along c-axis; lattice parameter reported at 293 K is 19.3712 Å.
18*	639	Dwivedi, G.L. and Subbarao, E.C.	1973	X	293,1073	α-Nb_2O_5	The above specimen; expansion measured along b-axis; lattice parameter reported at 293 K is 3.8236 Å.

* Not shown in figure.

SPECIFICATION TABLE 68. THERMAL LINEAR EXPANSION OF DINIOBIUM PENTAOXIDE Nb_2O_5 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
19*	640	Manning, W.R., Hunter, D., Jr., Calderwood, F.W., and Stacy, D.W.	1972	X	293-1604		99.95 pure monoclinic sample fabricated from a fine powder, average particle size < 5 μm; expansion measured along a-axis; lattice parameter reported at 293 K is 21.088 Å.
20*	640	Manning, W.R., et al.	1972	X	293-1609		The above specimen; expansion measured along b-axis; lattice parameter reported at 293 K is 3.831 Å.
21*	640	Manning, W.R., et al.	1972	X	293-1605		The above specimen; expansion measured along c-axis; lattice parameter reported at 293 K is 19.328 Å.
22	640	Manning, W.R., et al.	1972	L	293-1242	Sample D-2 Run 1	Similar to the above specimen except expansion measured using dilatometer; sintered sample of 36% porosity.
23	640	Manning, W.R., et al.	1972	L	1223-293	Sample D-2 Run 1	The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.012%; a hysteresis between heating and cooling data observed by authors.
24	640	Manning, W.R., et al.	1972	L	293-1458	Sample D-2 Run 2	The above specimen; expansion measured with increasing temperature.
25	640	Manning, W.R., et al.	1972	L	1428-293	Sample D-2 Run 2	The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.054%; a hysteresis between heating and cooling data observed by authors.
26	640	Manning, W.R., et al.	1972	L	293-1273	Sample D-5 Run 1	Similar to the above specimen except 22% porosity.
27	640	Manning, W.R., et al.	1972	L	1273-293	Sample D-5 Run 1	The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.025%; a hysteresis between heating and cooling data observed by authors.
28	640	Manning, W.R., et al.	1972	L	293-1473	Sample D-5 Run 2	The above specimen; expansion measured with increasing temperature.
29	640	Manning, W.R., et al.	1972	L	1423-293	Sample D-5 Run 2	The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.037%; a hysteresis between heating and cooling data observed by authors.
30	640	Manning, W.R., et al.	1972	L	293-1294	Sample D-10	Similar to the above specimen except 9% porosity; average of Runs 1, 2, and 3; expansion measured with increasing temperature.
31	640	Manning, W.R., et al.	1972	L	1173-293	Sample D-10	The above specimen; average of Runs 1, 2, and 3; expansion measured with decreasing temperature; a hysteresis between heating and cooling data observed by authors.
32	640	Manning, W.R., et al.	1972	L	293-1473	Sample D-10 Run 4	The above specimen; expansion measured with increasing temperature.
33	640	Manning, W.R., et al.	1972	L	1373-293	Sample D-10 Run 4	The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.016%; a hysteresis between heating and cooling data observed by authors.
34	640	Manning, W.R., et al.	1972	L	293-1273	Sample D-11	Similar to the above specimen except hot-pressed sample of 16% porosity; average of Runs 1 and 2 before additional heat treatment.
35	640	Manning, W.R., et al.	1972	L	1173-293	Sample D-11	The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.004%.

* Not shown in figure.

SPECIFICATION TABLE 68. THERMAL LINEAR EXPANSION OF DINIOBIUM PENTAOXIDE Nb_2O_5 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
36	640	Manning, W.R., Hunter, D., Jr., Calderwood, F.W., and Stacy, D.W.	1972	L	293-1480	Sample D-11 Run 3	The above specimen; expansion measured after the heat treatment.
37	640	Manning, W.R., et al.	1972	L	1473-293	Sample D-11 Run 3	The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.060%.

DATA TABLE 68. THERMAL LINEAR EXPANSION OF DINIOBIUM PENTAOXIDE Nb_2O_5

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
298	0.000
342	0.005
519	-0.009
679	-0.017
749	-0.026
883	-0.014
944	-0.004

CURVE 2

T	$\Delta L/L_0$
293	0.000*
473	0.019
573	0.035
673	0.054
773	0.075
873	0.094
973	0.111
1073	0.126
1173	0.140
1273	0.153

CURVE 3

T	$\Delta L/L_0$
293	0.000*
473	0.019*
573	0.037
673	0.058
773	0.080
873	0.102

CURVE 4*

T	$\Delta L/L_0$
873	0.097
773	0.077
673	0.058
573	0.036
473	0.019
293	0.000

CURVE 5*

T	$\Delta L/L_0$
293	0.000
473	0.023
573	0.042
673	0.063
773	0.085

CURVE 6*

T	$\Delta L/L_0$
773	0.085
673	0.062
573	0.041
473	0.022
293	0.000

CURVE 7*, †

T	$\Delta L/L_0$
527	0.000
574	-0.011
607	-0.016
645	-0.016
674	-0.013
773	0.000
873	0.018
974	0.040
1074	0.065
1144	0.085

CURVE 8

T	$\Delta L/L_0$
434	-0.016
473	-0.021
573	-0.030
672	-0.034
773	-0.028
873	-0.020
974	-0.003
1072	0.015
1148	0.029

CURVE 9

T	$\Delta L/L_0$
571	-0.026
588	-0.029
623	-0.034
651	-0.033
672	-0.029
773	-0.016
872	-0.004
973	0.012
1074	0.026
1141	0.037

CURVE 10

T	$\Delta L/L_0$
298	0.000*
541	-0.022
556	-0.029
574	-0.034
598	-0.039
623	-0.041
673	-0.041
774	-0.034
873	-0.024
974	-0.009
1074	0.008
1132	0.018

CURVE 11

T	$\Delta L/L_0$
348	-0.004
373	-0.007
474	-0.015
573	-0.023
672	-0.032
724	-0.029
774	-0.026
873	-0.016
973	-0.002*
1074	0.014*
1173	0.037

CURVE 12*

T	$\Delta L/L_0$
293	0.000
373	0.002
473	0.003
573	0.006
673	0.011
773	0.017
873	0.030
973	0.045
1073	0.061
1173	0.079
1235	0.090

CURVE 13*

T	$\Delta L/L_0$
293	0.00
1425	-0.10
1663	-0.17

CURVE 14*

T	$\Delta L/L_0$
293	0.00
1423	0.00
1663	0.45

CURVE 15*

T	$\Delta L/L_0$
293	0.00
1423	0.68
1663	0.68

CURVE 16*

T	$\Delta L/L_0$
293	0.00
1073	0.44

CURVE 17*

T	$\Delta L/L_0$
293	0.00
1073	0.46

CURVE 18*

T	$\Delta L/L_0$
293	0.00
1073	0.00

CURVE 19*

T	$\Delta L/L_0$
293	0.000
445	0.147
544	0.081
683	0.223
775	0.190
886	0.280
965	0.232
1053	0.375
1145	0.318
1190	0.474
1266	0.707
1272	0.488
1362	0.569
1465	0.749
1536	0.892
1604	0.616
1604	0.934

CURVE 20*

T	$\Delta L/L_0$
293	0.000

CURVE 20 (cont.)*

T	$\Delta L/L_0$
449	0.000
547	0.026
689	-0.235
779	0.026
891	-0.209
970	0.026
1059	0.026
1147	0.313
1187	0.052
1270	0.052
1282	0.313
1372	0.313

CURVE 21*

T	$\Delta L/L_0$
293	0.000
453	0.104
547	0.145
686	0.264
776	0.264
892	0.326
969	0.331
1057	0.419
1151	0.372
1188	0.543
1266	0.704
1283	0.704
1370	0.704
1458	0.543
1458	0.750
1542	0.900
1605	0.848
1605	0.900

CURVE 22

T	$\Delta L/L_0$
293	0.000*
323	0.000
373	0.006
423	0.019
473	0.020
523	0.023
573	0.032
623	0.032
673	0.040
723	0.049
773	0.067
823	0.080

CURVE 22 (cont.)

T	$\Delta L/L_0$
873	0.096
923	0.110
973	0.130
1023	0.149
1073	0.165
1123	0.181
1173	0.194
1223	0.205
1242	0.209

CURVE 23

T	$\Delta L/L_0$
1223	0.207
1173	0.187
1123	0.166
1073	0.143
1023	0.123
973	0.106
923	0.086
873	0.070
823	0.055
773	0.039
723	0.025
673	0.012
623	0.000
573	-0.012
523	-0.023
323	-0.012
293	0.000*

CURVE 24

T	$\Delta L/L_0$
293	0.000*
323	0.000*
373	0.000
423	0.000*
473	0.000
523	0.004
573	0.007
623	0.014
673	0.020
723	0.029
773	0.039*
823	0.051
873	0.062
923	0.079
973	0.097
1073	0.126*

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 68. THERMAL LINEAR EXPANSION OF DINIOBIUM PENTAOXIDE Nb_2O_5 (continued)

T	$\Delta L/L_0$
CURVE 24 (cont.)	
1123	0.146
1173	0.163
1223	0.182
1273	0.201
1323	0.216
1373	0.228
1423	0.242
1458	0.245
CURVE 25	
1428	0.279
1373	0.262
1323	0.241
1273	0.220
1223	0.196
1173	0.173
1123	0.149
1073	0.126*
1023	0.107
973	0.090
923	0.072
873	0.052
823	0.040
773	0.023
723	0.009
673	-0.005
623	-0.016
573	-0.023*
523	-0.029
473	-0.032
423	-0.027
373	-0.021
323	-0.006
293	0.000*
CURVE 26	
293	0.000*
323	0.002
373	-0.002
423	-0.003
473	-0.003
523	-0.002
573	-0.005
623	-0.007
673	-0.005
723	-0.002

T	$\Delta L/L_0$
CURVE 26 (cont.)	
773	0.009
823	0.016
873	0.028
923	0.039
973	0.051
1023	0.069
1073	0.085
1123	0.100
1173	0.115
1223	0.132
1273	0.146
CURVE 27	
1273	0.177
1223	0.152
1173	0.132
1123	0.109
1073	0.092
1023	0.073
973	0.054
923	0.039*
873	0.023
823	0.009
773	-0.003
723	-0.017
673	-0.032*
623	-0.045
573	-0.057
473	-0.046
423	-0.042
373	-0.025
323	-0.006*
293	0.000*
CURVE 28	
293	0.000*
323	-0.002*
373	-0.004
423	-0.007
473	-0.009
523	-0.009
573	-0.009
623	-0.003
673	0.000
723	0.005
773	0.015*

T	$\Delta L/L_0$
CURVE 28 (cont.)	
823	0.027
873	0.038
923	0.049
973	0.062
1023	0.079
1073	0.095
1123	0.114
1173	0.132*
1223	0.151*
1273	0.171
1323	0.190
1373	0.205
1423	0.223
1473	0.235
CURVE 29	
1423	0.253
1373	0.236
1323	0.214
1273	0.191
1173	0.137
1123	0.115*
1073	0.094*
1023	0.075
973	0.055*
923	0.034
873	0.017
823	0.002
773	-0.017
723	-0.034
673	-0.051
623	-0.062
573	-0.070
523	-0.078
473	-0.075
423	-0.059
373	-0.038
323	-0.012*
293	0.000*
CURVE 30	
293	0.000*
323	0.003
373	-0.004
423	-0.010
473	-0.018

T	$\Delta L/L_0$
CURVE 30 (cont.)	
523	-0.022
573	-0.027*
623	-0.035*
673	-0.037
723	-0.037
773	-0.034*
823	-0.029
873	-0.025*
923	-0.021
973	-0.015
1023	-0.005
1073	0.006
1123	0.021
1173	0.035
1223	0.051
1273	0.071
1294	0.081
CURVE 31	
1173	0.032
1123	0.009
1073	-0.011
1023	-0.031
973	-0.050
923	-0.070
873	-0.086
823	-0.099
773	-0.116
723	-0.126*
673	-0.140*
623	-0.139*
573	-0.124*
523	-0.099
473	-0.074*
423	-0.051
373	-0.029
323	-0.008
293	0.000*
CURVE 32	
293	0.000*
323	0.000*
373	-0.010
423	-0.014
473	-0.016*
523	-0.016

T	$\Delta L/L_0$
CURVE 32 (cont.)	
573	-0.020
623	-0.022
673	-0.022
723	-0.022
773	-0.015*
823	-0.010
873	-0.006
923	0.002
973	0.006
1023	0.013
1073	0.021
1123	0.033
1173	0.047
1223	0.059
1323	0.088
1373	0.107
1423	0.120
1473	0.134
CURVE 33	
1373	0.118
1323	0.099
1273	0.080
1223	0.057
1173	0.035*
1125	0.018
1074	-0.003
1023	-0.024
973	-0.042
926	-0.054
879	-0.070
825	-0.086
773	-0.102
723	-0.117
673	-0.129*
623	-0.134*
573	-0.118
523	-0.094
473	-0.072
423	-0.048
373	-0.026
323	-0.004*
293	0.000*
CURVE 34	
293	0.000*

T	$\Delta L/L_0$
CURVE 34 (cont.)	
323	0.000*
373	0.000*
423	0.000
473	0.005
523	0.010
573	0.016
623	0.021
673	0.030
723	0.039
773	0.054
823	0.068
873	0.084
923	0.098
973	0.115
1023	0.133
1073	0.147
1123	0.163
1173	0.180
1223	0.198
1273	0.214
CURVE 35	
1173	0.182
1123	0.164
1073	0.145*
1023	0.130
973	0.112*
923	0.097
873	0.083*
823	0.071
773	0.061
723	0.049*
673	0.038
623	0.024
573	0.015
523	0.006
473	0.002
423	-0.004
373	-0.007*
323	-0.003
293	0.000*
CURVE 36	
293	0.000*
323	0.005*
373	-0.001*

* Not shown in figure.

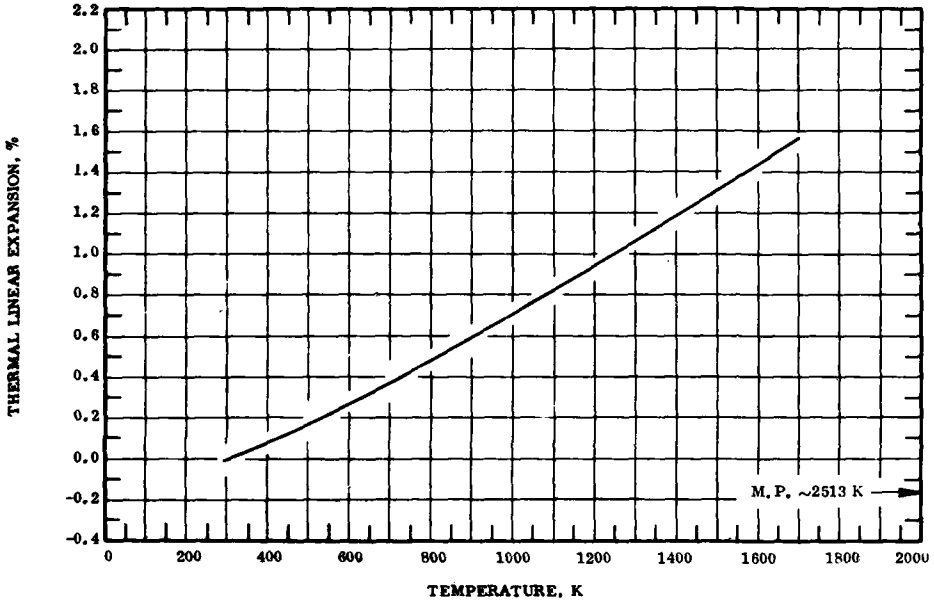
DATA TABLE 68. THERMAL LINEAR EXPANSION OF DINIOBIUM PENTAOXIDE Nb_2O_5 (continued)

T	$\Delta L/L_0$
CURVE 36 (cont.)	
423	-0.005*
473	-0.003
523	0.000
573	0.008*
623	0.017
673	0.024
723	0.035
773	0.044
823	0.057
873	0.070*
923	0.085*
973	0.099
1023	0.112
1073	0.123
1123	0.134
1173	0.148
1223	0.163
1273	0.175
1323	0.186
1373	0.201
1423	0.207
1473	0.213
1480	0.210
CURVE 37	
1473	0.265
1423	0.242*
1373	0.226
1323	0.208
1273	0.188
1223	0.165
1173	0.142
1123	0.124
1073	0.104
1023	0.085
973	0.073
923	0.057
873	0.042
823	0.030
773	0.012
723	-0.002*
673	-0.013
623	-0.027
573	-0.036
523	-0.042
473	-0.046*
423	-0.043

T	$\Delta L/L_0$
CURVE 37 (cont.)	
373	-0.036
323	-0.020
293	0.000*

* Not shown in figure.

FIGURE AND TABLE NO. 69R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF PLUTONIUM DIOXIDE PuO_2



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	8.1
400	0.090	8.8
500	0.181	9.4
600	0.278	10.0
700	0.381	10.5
800	0.488	10.9
900	0.600	11.3
1000	0.713	11.6
1100	0.831	11.9
1200	0.950	12.0
1300	1.071	12.2
1400	1.200	12.5
1500	1.316	12.6
1600	1.438	12.8
1700	1.560	13.0

REMARKS

The recommended values are based on the data reported in curves 2, 3, 5, 9 and 15 and are considered accurate to within ±3%. The lattice parameter at 293 K reported in curves 6 and 14 is rather high which results in the lower thermal expansion values in these two curves. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.203 + 5.692 \times 10^{-4}\ T + 4.501 \times 10^{-7}\ T^2 - 1.031 \times 10^{-10}\ T^3$$

The tabulated values for the coefficient of thermal expansion are derived from the experimental data and are considered accurate to about ±5%.

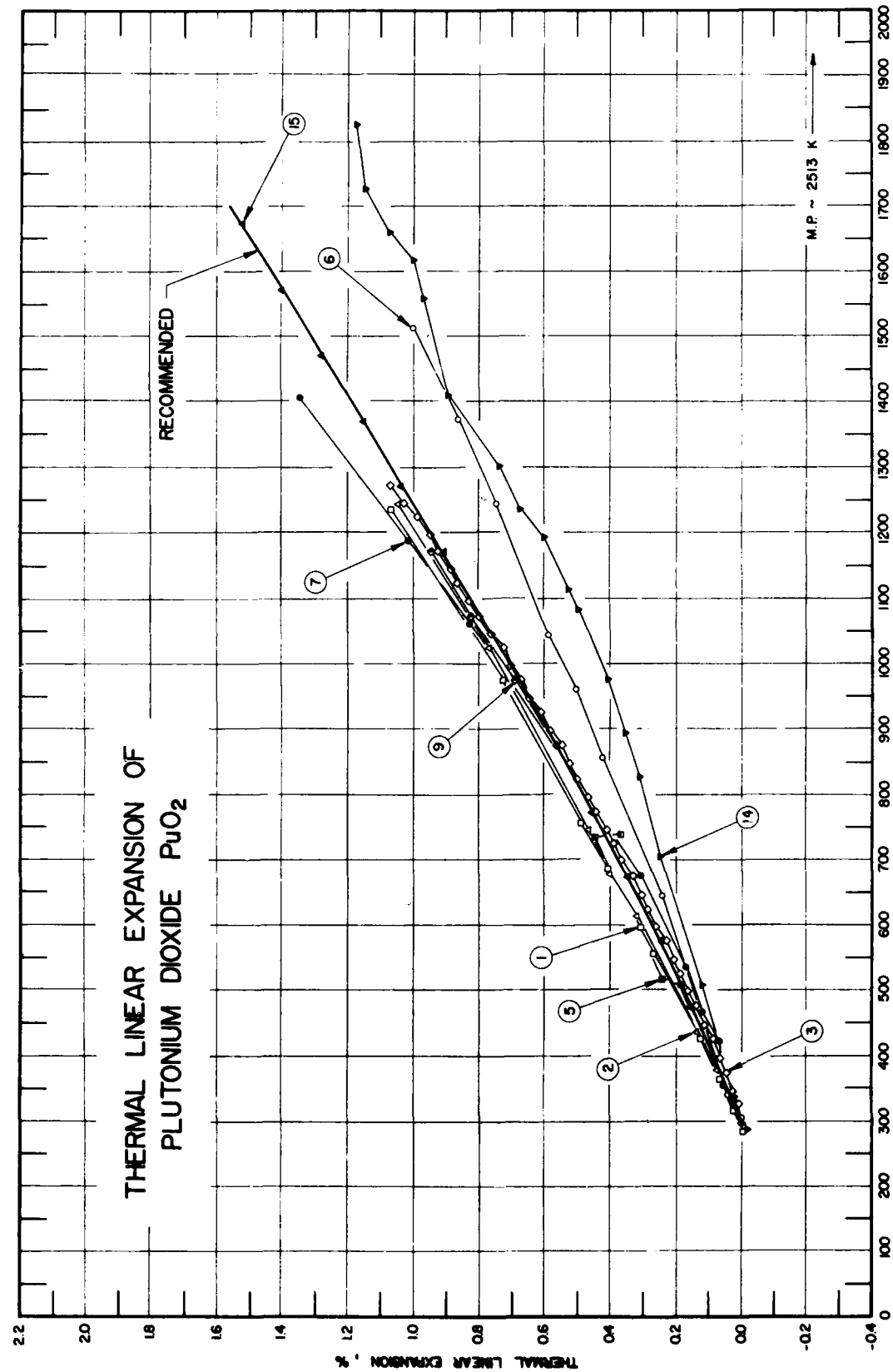

THERMAL LINEAR EXPANSION OF
PLUTONIUM DIOXIDE PuO_2
RECOMMENDED
M.P. ~ 2513 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
5
6
7
9
14
15

FIGURE 69

SPECIFICATION TABLE 69. THERMAL LINEAR EXPANSION OF PLUTONIUM DIOXIDE PuO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	139	Ferguson, I. F., Street, R. S., and D' Eye, R. W. M.	1960	X	283-1237		Crystalline specimen; prepared by heating a gram of plutonia in argon atmosphere at 1873 K for several days, ground, heated in CO atmosphere at 1123 K for 4 hr and then quenched in CO atmosphere to room temperature; expansion measured with CuKα radiation; platinum mixed as internal standard; lattice parameter reported at 283.2 K is 5.3947 Å; 5.3950 Å at 293.2 K determined by graphical interpolation.
2	139	Ferguson, I. F., et al.	1960	X	283-1243	$PuO_{2.009}$	About one hundred mg of stoichiometric plutonia as the above specimen heated in air atmosphere at 1123 K for several hr, cooled quickly in air atmosphere to room temperature; platinum mixed as internal standard; lattice parameter reported at 283.2 K is 5.3948 Å; 5.3950 Å at 293.2 K determined by graphical interpolation.
3	45	Brett, N. H. and Russell, L. E.	1960	L	298-1273		Powdered specimen; 5 mm diameter, 12.7 mm long; prepared by compacting at 3000 kg cm^{-2} with 5% naphthalene binder; sintered at 1773 K in hydrogen atmosphere for 2 hr, then at 1473 K in air atmosphere; ends of pellet ground flat; density 10.08 g cm^{-3}; average value of five tests; zero-point correction of 0.0050% determined by graphical extrapolation.
4*	45	Brett, N. H. and Russell, L. E.	1960	L	298-1273	$PuO_{1.77}$	Specimen 12.8 mm long; prepared by reheating the above-mentioned Pu_2 pellet at 1773 K in hydrogen atmosphere for 3 hr; weight change corresponded to composition of about $PuO_{1.77}$ and x-ray pattern showed equal amounts of PuO_2 and α-Pu_2O_3 phases; bulk density 9.70 g cm^{-3}; zero-point correction of ±0.0000% determined by graphical extrapolation.
5	141	Mardon, P. G. and Waldron, M. B.	1957	X	293-739		Lattice parameter reported at 293.2 K is 5.393±0.002 Å.
6	142	Roth, J. and Halteman, E. K.	1965	X	304-1513		Specimen prepared by precipitation of oxalate; ThO_2 used as internal standard; lattice parameter reported at 304.2 K is 5.4031 Å; 5.4028 Å at 293.2 K determined by graphical extrapolation.
7	142	Roth, J. and Halteman, E. K.	1965	X	356-1408		Specimen prepared by precipitation of hydroxide; ThO_2 used as internal standard; lattice parameter reported at 356.2 K is 5.3958 Å; 5.3925 Å at 293.2 K determined by graphical extrapolation.
8*	338	Leblanc, J. M. and Andriessen, H.	1962	L	293-1273	$PuO_{2.036}$	Pellet specimen; prepared by sintering powder; averaged value of 3 cycles reported.
9	338	Leblanc, J. M. and Andriessen, H.	1962	L	293-1273	PuO_2	Similar to the above specimen.
10*	338	Leblanc, J. M. and Andriessen, H.	1962	L	293-1273	$PuO_{1.95}$	Similar to the above specimen.
11*	338	Leblanc, J. M. and Andriessen, H.	1962	L	293-1273	$PuO_{1.81}$	Similar to the above specimen.
12*	338	Leblanc, J. M. and Andriessen, H.	1962	L	293-1273	$PuO_{1.74}$	Similar to the above specimen.
13*	338	Leblanc, J. M. and Andriessen, H.	1962	L	293-1273	$PuO_{1.71}$	Similar to the above specimen.
14	343	Desando, R. J., Wyder, W. C., Eckstein, R. R., and Amos, W. R.	1970	X	287-1778	$^{238}PuO_2$	Microsphere specimen; 50-250 μm diameter; obtained by passage of polycrystalline $^{238}PuO_2$ through induction-coupled plasma torch; temperature determined with platinum calibration or optical pyrometer; lattice parameter reported at 287 K is 5.4158 Å; 5.4167 Å at 293 K determined by graphical interpolation; coefficient of thermal linear expansion also reported.
15	651	Tokar, M., Nutt, A. W., and Keenan, T. K.	1973	L	298-1693	$^{239}PuO_2$	Plutonium oxalate powder was calcinated at 600 C and unidirectionally cold pressed at 10 tsi, using 1 wt.% Carbowax 4000 as a binder; the as-pressed specimen was 0.36 x 0.63 x 10 cm; sintered at 1475 C for 6 hr in CO_2 to a density of 10.67 g cm^{-3}; ultrasonically machined to 0.326 x 0.552 x 5.027 cm; zero-point correction is 0.0050%; coefficient of thermal linear expansion also reported.

* Not shown in figure.

DATA TABLE 69. THERMAL LINEAR EXPANSION OF PLUTONIUM DIOXIDE PuO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
283	-0.0055
313	0.0296
365	0.0741
423	0.1353
558	0.2780
595	0.3132
685	0.4096
758	0.4967
971	0.7265
1237	1.0639

CURVE 2

T	$\Delta L/L_0$
283	-0.0037*
378	0.0815
433	0.1427
611	0.3225
678	0.4022
749	0.4708
1023	0.7710
1243	1.0436

CURVE 3

T	$\Delta L/L_0$
298	0.0050
323	0.0160
348	0.0340
373	0.0530
398	0.0745
423	0.0960
448	0.1200
473	0.1430
498	0.1660
523	0.1905
548	0.2125
573	0.2395
598	0.2625
623	0.2905
648	0.3145
673	0.3405
698	0.3655
723	0.3935
748	0.4195
773	0.4465
798	0.4725
823	0.5020
848	0.5280

CURVE 3 (cont.)

T	$\Delta L/L_0$
873	0.5580
898	0.5815
923	0.6135
948	0.6445
973	0.6730
998	0.7035
1023	0.7350
1048	0.7670
1073	0.8000
1098	0.8315
1123	0.8640
1148	0.8900
1173	0.9260
1198	0.9565
1223	0.9910
1248	1.0300
1273	1.0680

CURVE 4*

T	$\Delta L/L_0$
298	0.0050
323	0.0050
348	0.0225
373	0.0425
398	0.0625
423	0.0850
448	0.1075
473	0.1325
498	0.1600
523	0.1875
548	0.2175
573	0.2525
598	0.2950
613	0.3225
623	0.3475
633	0.3675
648	0.3950
673	0.4375
698	0.4700
723	0.5050
748	0.5425
773	0.5775
798	0.6100
823	0.6450
848	0.6800
873	0.7175
898	0.7500

CURVE 4 (cont.)*

T	$\Delta L/L_0$
923	0.7850
933	0.8225
943	0.8600
948	0.8725
973	0.9200
998	0.9550
1023	0.9900
1048	1.0225
1073	1.0525
1098	1.0850
1123	1.1175
1148	1.1475
1173	1.1825
1198	1.2175
1223	1.2500
1248	1.2825
1273	1.3250

CURVE 5

T	$\Delta L/L_0$
293	0.0000*
396	0.0741*
508	0.1854
513	0.2411
731	0.4450
739	0.3709

CURVE 6

T	$\Delta L/L_0$
304	0.0055
340	0.0425
398	0.0814
648	0.2461
858	0.4257
960	0.5108
1046	0.5885
1248	0.7459
1375	0.8643
1513	1.0013

CURVE 7

T	$\Delta L/L_0$
356	0.0611
420	0.0797
466	0.1242
533	0.1798
676	0.3133

CURVE 7 (cont.)

T	$\Delta L/L_0$
1063	0.8289
1190	1.0162
1408	1.3556

CURVE 8*

T	$\Delta L/L_0$
293	0.000
373	0.078
473	0.176
573	0.297
673	0.433
773	0.576
873	0.713
973	0.857
1073	1.022
1173	1.179
1273	1.333

CURVE 9

T	$\Delta L/L_0$
293	0.000*
373	0.062*
473	0.139*
573	0.249
673	0.342*
773	0.442*
873	0.563
973	0.694
1073	0.827
1173	0.950
1273	1.068*

CURVE 10*

T	$\Delta L/L_0$
293	0.000
373	0.067
473	0.146
573	0.246
673	0.353
773	0.461
873	0.597
973	0.768
1073	0.897
1173	1.021
1273	1.137

CURVE 11*

T	$\Delta L/L_0$
293	0.000
373	0.056
473	0.139
573	0.288
673	0.448
773	0.581
873	0.737
973	0.945
1073	1.061
1173	1.153
1273	1.274

CURVE 12*

T	$\Delta L/L_0$
293	0.000
373	0.066
473	0.160
573	0.263
673	0.475
773	0.595
873	0.725
973	0.877
1073	0.991
1173	1.118
1273	1.245

CURVE 13*

T	$\Delta L/L_0$
293	0.000
373	0.049
473	0.130
573	0.300
673	0.478
773	0.595
873	0.719
973	0.850
1073	0.975
1173	1.091
1273	1.215

CURVE 14

T	$\Delta L/L_0$
287	-0.0166
338	0.0239
508	0.1255
702	0.2510

CURVE 14 (cont.)

T	$\Delta L/L_0$
828	0.3175
896	0.3655
975	0.4079
1085	0.5039
1110	0.5316
1197	0.6092
1235	0.6775
1304	0.7366
1410	0.9046
1563	0.9729
1618	1.0283
1663	1.0726
1728	1.1464
1778	1.1686

CURVE 15

T	$\Delta L/L_0$
298	0.0050*
373	0.0738*
473	0.1632
573	0.2587*
673	0.3591
773	0.4633
873	0.5710*
973	0.6821*
1073	0.7965*
1173	0.9143
1273	1.0352
1373	1.1587
1473	1.2838
1573	1.4088
1673	1.5282

* Not shown in figure.

DATA TABLE 69. COEFFICIENT OF THERMAL LINEAR EXPANSION OF PLUTONIUM DIOXIDE PuO_2

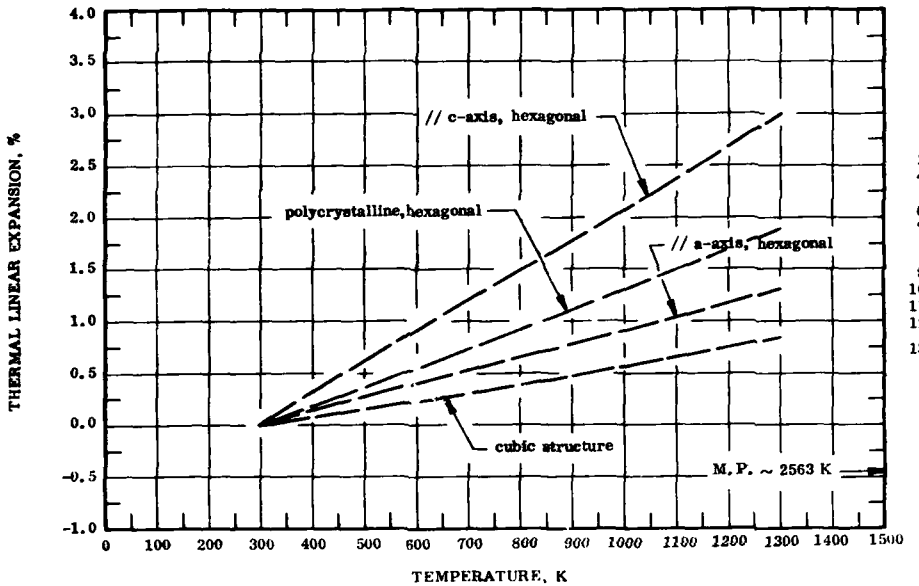
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3*	
373	8.06
473	9.42
573	9.87
673	10.20
773	10.97
873	11.48
973	12.54
1073	12.70
1173	12.70
1273	14.4
CURVE 4*	
373	7.91
473	10.55
573	14.68
673	14.79
773	13.70
873	13.94
973	16.04
1073	12.27
1173	14.03
1273	17.53
CURVE 14	
321	6.13
369	6.08
420	6.23
466	6.14
518	6.28
568	6.28
617	6.28
671	6.28
718	6.28
769	6.28
818	6.28
871	6.28
918	6.28
966	7.37
1017	7.76
1068	8.51
1119	9.23
1168	10.17
1217	11.91
1270	12.57

T	α
CURVE 14 (cont.)	
1317	13.89
1364	15.43
1399	17.50*
CURVE 15*	
373	8.54
473	9.28
573	9.86
673	10.24
773	10.60
873	10.93
973	11.27
1073	11.81
1173	11.94
1273	12.23
1373	12.45
1473	12.54
1573	12.73

* Not shown in figure.

FIGURE AND TABLE NO. 70R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF DIPRASEODYMIUM TRIOXIDE Pr_2O_3



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Hexagonal structure				Cubic structure	
	// c-axis	// a-axis	polycrystalline			
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	0.000	0.000	18.1	0.000	7.8
400	0.317	0.140	0.199	18.1	0.082	7.8
500	0.612	0.268	0.383	18.1	0.157	7.8
600	0.907	0.395	0.566	18.1	0.235	7.8
700	1.202	0.521	0.748	18.1	0.307	7.8
800	1.497	0.647	0.930	18.3	0.385	7.9
900	1.794	0.775	1.115	18.5	0.466	8.3
1000	2.091	0.905	1.301	18.7	0.551	8.7
1100	2.390	1.038	1.489	19.0	0.641	8.8
1200	2.692	1.175	1.681	19.5	0.737	9.0
1300	3.000	1.318	1.879	19.6	0.840	9.2

REMARKS

The provisional values for the polycrystalline sample of hexagonal structure are calculated from the selected axial thermal expansion values. The provisional values for the cubic structure sample are based on the data reported in curve 1. These values are considered accurate to within ± 10% and are represented approximately by the following equations:

Hexagonal structure:

// c-axis: $\Delta L/L_0 = -0.875 + 3.012 \times 10^{-3} T - 1.102 \times 10^{-7} T^2 + 6.417 \times 10^{-11} T^3$

// a-axis: $\Delta L/L_0 = -0.409 + 1.475 \times 10^{-3} T - 3.232 \times 10^{-7} T^2 + 1.613 \times 10^{-10} T^3$

polycrystalline: $\Delta L/L_0 = -0.566 + 1.998 \times 10^{-3} T - 2.698 \times 10^{-7} T^2 + 1.377 \times 10^{-10} T^3$

Cubic structure: $\Delta L/L_0 = -0.242 + 8.919 \times 10^{-4} T - 2.775 \times 10^{-7} T^2 + 1.782 \times 10^{-10} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 10%.

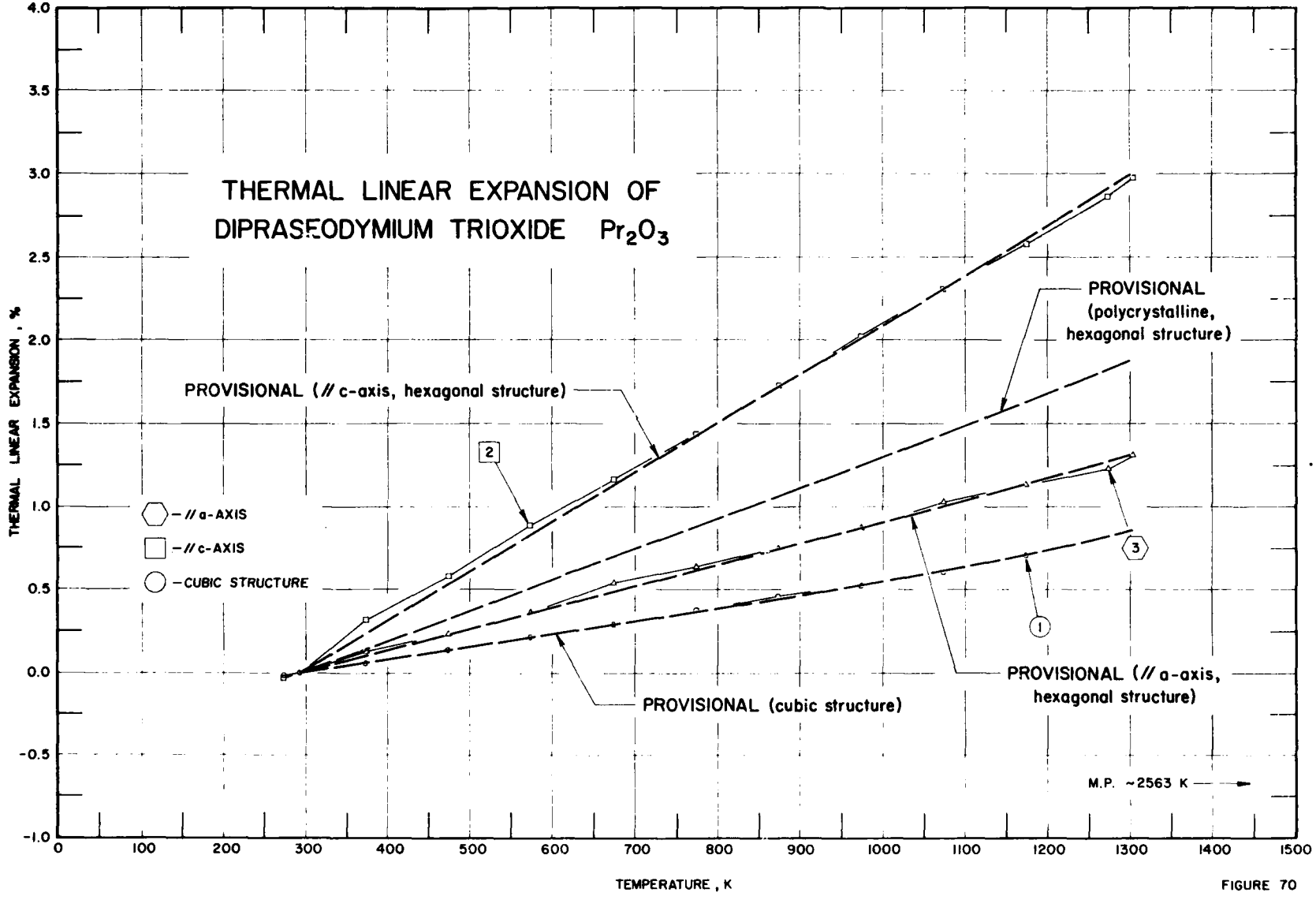

THERMAL LINEAR EXPANSION OF
DIPRASEODYMIUM TRIOXIDE Pr_2O_3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
PROVISIONAL (// c-axis, hexagonal structure)
PROVISIONAL
(polycrystalline,
hexagonal structure)
PROVISIONAL (// a-axis,
hexagonal structure)
PROVISIONAL (cubic structure)
2
3
1
— // a-AXIS
— // c-AXIS
— CUBIC STRUCTURE
M.P. ~2563 K

FIGURE 70

SPECIFICATION TABLE 70. THERMAL LINEAR EXPANSION OF DIPRASEODYMIUM TRIOXIDE Pr_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	590	Rudenko, V.S. and Boganov, A.G.	1970	X	273-1173		Transition temperature from cubic structure to hexagonal structure at 1153 K with volume construction ~7.1%; lattice parameter of cubic structure is 11.145 Å at 273 K; 11.146 Å at 293 K determined by graphical interpolation.
2	590	Rudenko, V.S. and Boganov, A.G.	1970	X	273-1304		Similar to the above specimen; lattice parameter along c-axis of hexagonal structure is 6.024 Å at 273 K; 6.026 Å at 293 K determined by graphical interpolation.
3	590	Rudenko, V.S. and Boganov, A.G.	1970	X	273-1301		The above specimen; lattice parameter along a-axis of hexagonal structure is 3.861 Å at 273 K; 3.862 Å at 293 K determined by graphical interpolation.

DATA TABLE 70. THERMAL LINEAR EXPANSION OF DIPRASEODYMIUM TRIOXIDE Pr_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
273	-0.009
293	0.000
373	0.054
473	0.143
573	0.224
673	0.296
773	0.377
873	0.457
973	0.529
1073	0.610
1173	0.709
CURVE 2	
273	-0.033
293	0.000*
373	0.315
473	0.581
CURVE 2 (cont.)	
573	0.896
673	1.162
773	1.444
873	1.726
973	2.024
1073	2.307
1173	2.589
1273	2.871
1304	2.987
CURVE 3	
273	-0.026*
293	0.000*
373	0.129
473	0.233
573	0.362
CURVE 3 (cont.)	
673	0.544
773	0.647
873	0.751
973	0.880
1073	1.036
1173	1.139
1273	1.243
1301	1.320

* Not shown in figure.

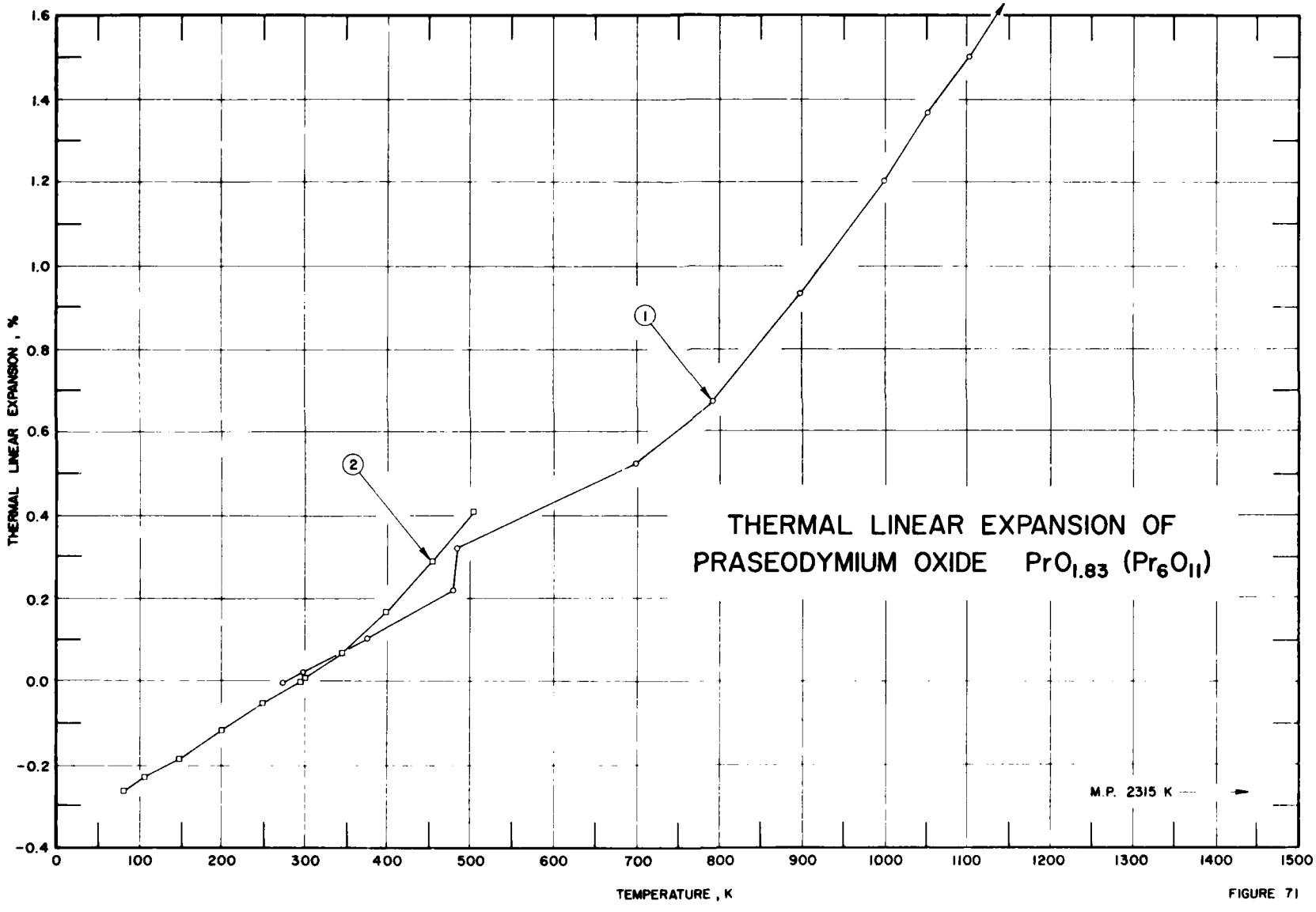

THERMAL LINEAR EXPANSION OF
PRASEODYMIUM OXIDE $PrO_{1.83}$ (Pr_6O_{11})
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
M.P. 2315 K
1
2
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 71

SPECIFICATION TABLE 71. THERMAL LINEAR EXPANSION OF PRASEODYMIUM OXIDE $PrO_{1.83}$ (Pr_6O_{11})

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	68	Stecura, S. and Campbell, W.J.	1961	X	273-1293	Pr_6O_{11}	99.9 pure; major non-rare-earth impurity was calcium; specimen obtained from Lindsay Chemical Co.; sintered at 1223 K for 24 hr; packed into alumina holder, sintered at 1323 K for 12 hr, cooled to 573 K and placed in vacuum desiccator for storage; expansion measured from 1022 line; unit cell parameter reported at 273.2 K is 10.9055 Å; zero-point correction of -0.006% determined by graphical interpolation.
2	594	Hatibarua, J. and Mahanta, P.C.	1971	X	77-1300	Pr_6O_{11}	Specimen 99.98 pure, 0.0008 Fe, 0.0005 Si, 0.01 Yt_2O_3; from Johnson and Matthey.

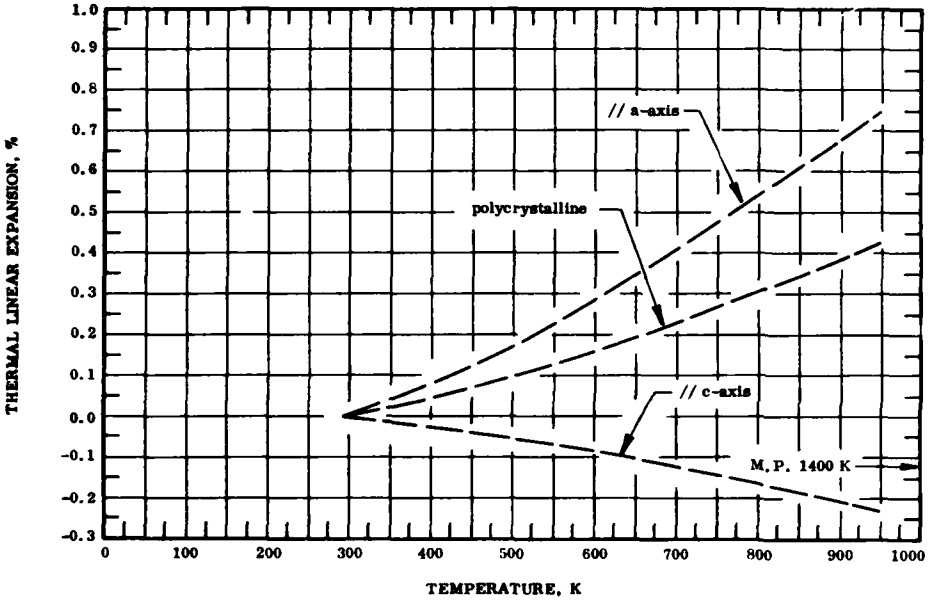
DATA TABLE 71. THERMAL LINEAR EXPANSION OF PRASEODYMIUM OXIDE $PrO_{1.83}$ (Pr_6O_{11})

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2	
273	-0.006	80	-0.263
298	0.021	106	-0.233
374	0.109	149	-0.182
479	0.222	200	-0.118
481	0.321	250	-0.055
699	0.522	293	0.000
793	0.674	300	0.009
898	0.933	345	0.074
999	1.201	397	0.172
1051	1.370	453	0.297
1103	1.507	502	0.414
1159	1.677*		
1223	1.818*		
1262	1.900*		
1293	1.952*		

* Not shown in figure.

FIGURE AND TABLE NO. 72R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF RUTHENIUM DIOXIDE RuO_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	3.6
350	0.041	-0.012	0.023	4.3
400	0.081	-0.024	0.047	4.9
450	0.127	-0.037	0.071	5.4
500	0.176	-0.052	0.100	5.9
550	0.230	-0.067	0.131	6.3
600	0.286	-0.084	0.162	6.7
650	0.350	-0.103	0.197	7.0
700	0.410	-0.122	0.233	7.2
750	0.475	-0.142	0.270	7.4
800	0.541	-0.163	0.307	7.6
850	0.607	-0.185	0.343	7.7
900	0.676	-0.207	0.382	7.7
950	0.750	-0.230	0.423	7.7

REMARKS

The provisional values for the polycrystalline sample are calculated from the selected axial thermal expansion values. These values are considered accurate to within ±10% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.083 - 1.266 \times 10^{-4}\,T + 1.560 \times 10^{-6}\,T^2 - 5.322 \times 10^{-10}\,T^3$

// c-axis: $\Delta L/L_0 = 0.023 + 3.722 \times 10^{-5}\,T - 4.292 \times 10^{-7}\,T^2 + 1.156 \times 10^{-10}\,T^3$

polycrystalline: $\Delta L/L_0 = -0.042 - 1.074 \times 10^{-4}\,T + 9.564 \times 10^{-7}\,T^2 - 3.471 \times 10^{-10}\,T^3$

The tabulated values for the coefficient of thermal expansion are derived from the experimental data and are considered accurate to about ±10%.

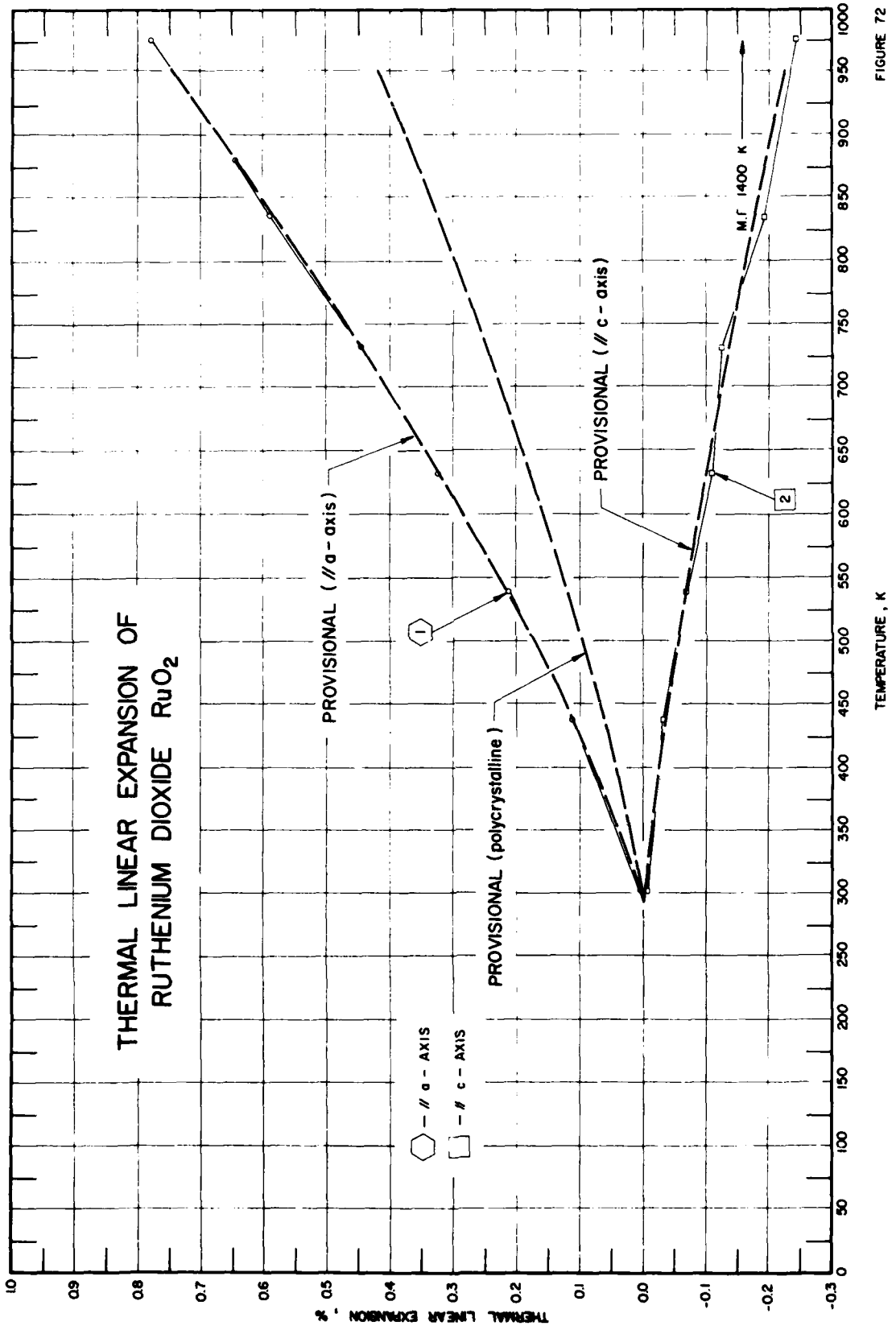

THERMAL LINEAR EXPANSION OF
RUTHENIUM DIOXIDE RuO_2
PROVISIONAL (// a - axis)
PROVISIONAL (// c - axis)
PROVISIONAL (polycrystalline)
M.P. 1400 K
1
2
— // a - AXIS
— // c - AXIS
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K

FIGURE 72

SPECIFICATION TABLE 72. THERMAL LINEAR EXPANSION OF RUTHENIUM DIOXIDE RuO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	140	Rao, K.V.K. and Iyengar, L.	1969	X	303-975		Specimen prepared by coating powder on quartz fibre with Araldite; expansion measured along a-axis; lattice parameter reported at 303.2 K is 4.4909 Å; 4.4906 Å at 293.2 K determined by graphical extrapolation; coefficient of thermal linear expansion also tabulated.
2	140	Rao, K.V.K. and Iyengar, L.	1969	X	303-975		The above specimen; expansion measured along c-axis; lattice parameter reported at 303.2 K is 3.1064 Å; 3.1071 Å at 293.2 K determined by graphical extrapolation; coefficient of thermal linear expansion also tabulated.

DATA TABLE 72. THERMAL LINEAR EXPANSION OF RUTHENIUM DIOXIDE RuO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 2 (cont.)	
303	0.0066	881	0.6502	438	-0.0289
438	0.1158	975	0.7838	540	-0.0643
540	0.2160			634	-0.1094
634	0.3273	CURVE 2		734	-0.1223
734	0.4520			836	-0.1898
836	0.5945	303	-0.0225	881	-0.2027
				975	-0.2446

DATA TABLE 72. COEFFICIENT OF THERMAL LINEAR EXPANSION OF RUTHENIUM DIOXIDE RuO_2

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α
CURVE 1		CURVE 1 (cont.)		CURVE 2 (cont.)*	
323	7.96	843	14.20	603	-3.30
363	8.30	883	13.69	643	-3.54
403	8.52	923	13.75	683	-3.86
443	9.13			723	-4.19
483	9.69	CURVE 2*		763	-4.51
523	10.30			803	-4.75
563	10.74	323	-1.53	843	-5.07
603	11.25	363	-1.77	883	-5.31
643	11.91	403	-2.01	923	-5.71
683	12.64	443	-2.25		
723	13.47	483	-2.41		
763	14.08	523	-2.74		
803	14.14	563	-2.90		

*Not shown in figure.

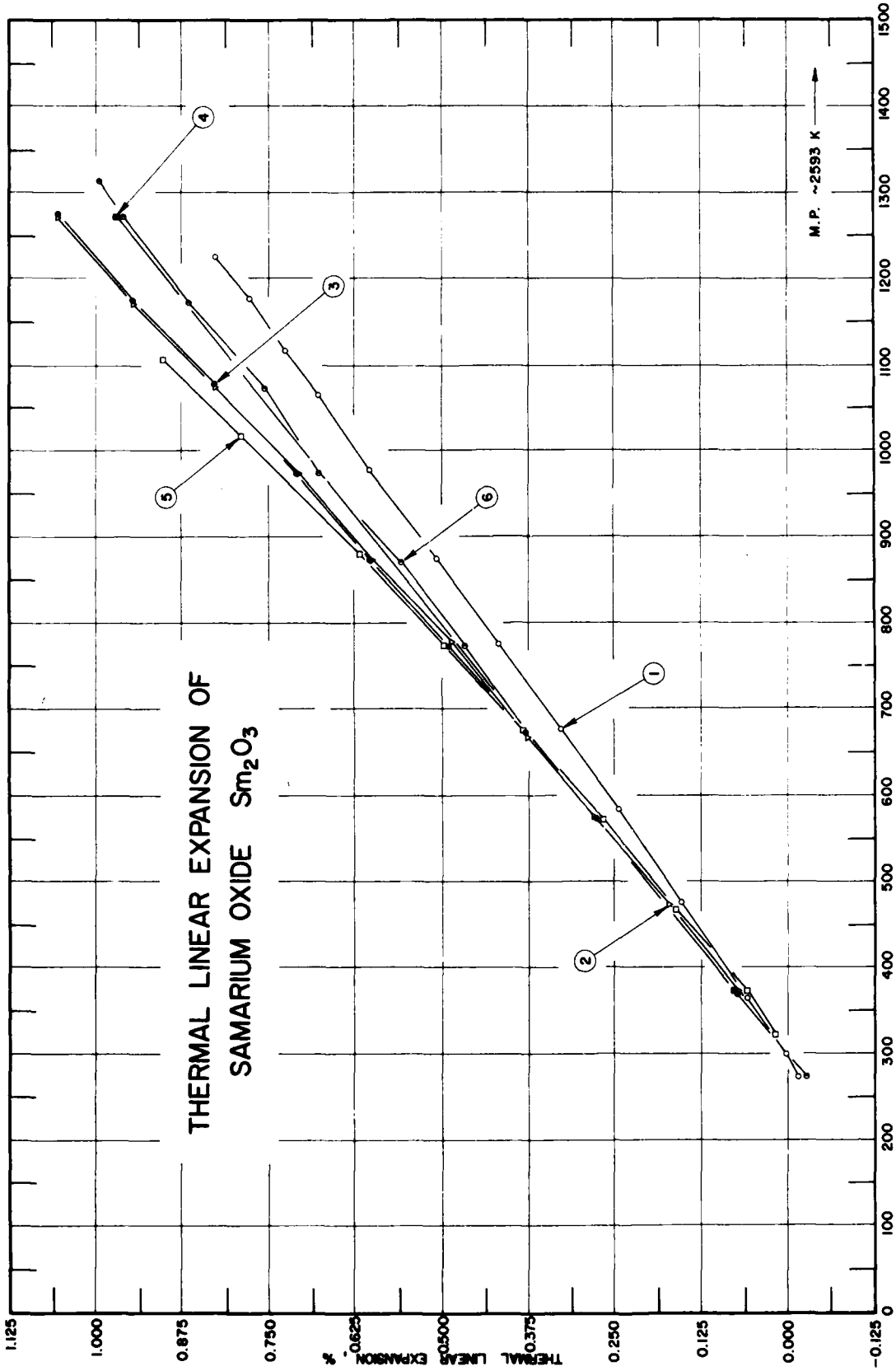

THERMAL LINEAR EXPANSION OF
SAMARIUM OXIDE Sm_2O_3
M.P. ~2593 K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.125
1.000
0.875
0.750
0.625
0.500
0.375
0.250
0.125
0.000
-0.125
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1
2
3
4
5
6

FIGURE 73

SPECIFICATION TABLE 73. THERMAL LINEAR EXPANSION OF SAMARIUM OXIDE Sm_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	68	Stecura, S. and Campbell, W.J.	1961	X	273-1223		99.9 pure; cubic phase specimen obtained from Lindsay Chemical Co.; sintered at 1023 K for 24 hr; packed in alumina holder, sintered at 1173 K for 24 hr, cooled to 573 K and stored in vacuum; unit cell parameter reported at 273.2 K is 10.9085 Å; zero-point correction of -0.017% determined by graphical interpolation.
2	14	Wilfong, R.J., Domingues, L.P., Furlong, L.R., and Finlayson, J.A.	1963	I	298-1273		0.03-0.3 Ca, Cu, 0.003-0.03 Si, and 0.001-0.01 Mg; monoclinic specimen calcined at 1773 K for 1 hr, mixed with binder (2% varsol plus 2% paraffin dissolved in benzene), hot pressed at 2873 K, ground into shape, matured at 1773 K for 1 hr, reground, heated to 1773 K for 1 hr and desiccated; bulk density 7.3 g cm^{-3} after test; heating rate 5 C per min; zero-point correction of 0.0046% determined by graphical extrapolation.
3	14	Wilfong, R.L., et al.	1963	I	298-1276		The above specimen; expansion measured on second test; zero-point correction of 0.0046% determined by graphical extrapolation.
4	103	Curtis, C.E. and Johnson, J.R.	1957	L	373,1273		Specimen pressed into bar at 2700 psi from fairly pure Sm_2O_3 powder, 5% water and 2% dextrin, and then sintered at 1773 K for 2 hr; density increased to 7.4 g cm^{-3}.
5	87	Ploetz, G.L., Krystyniak, C.W., and Dumas, H.E.	1958	I	322-1108		Monoclinic specimen; cut from pellet; hot pressed; 95% theoretical density; heating rate 3 to 5 C per min; zero-point correction of 0.007% determined by graphical extrapolation.
6	590	Rudenko, V.S. and Boganov, A.G.	1970	X	273-1312		Low temperature cubic forms undergo transition at 1253 K directly to the high temperature monoclinic forms; lattice parameter of cubic structure 10.937 Å at 293 K.

DATA TABLE 73. THERMAL LINEAR EXPANSION OF SAMARIUM OXIDE Sm_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
273	-0.017
299	0.005
365	0.061
473	0.153
581	0.243
676	0.326
777	0.417
877	0.510
976	0.601
1065	0.684
1116	0.727
1178	0.779
1223	0.827

CURVE 2

T	$\Delta L/L_0$
298	0.0046
372	0.0730
471	0.1710
575	0.2787
669	0.3779
771	0.4870
873	0.5982
971	0.7092
1073	0.8255
1171	0.9399
1273	1.0590

CURVE 3

T	$\Delta L/L_0$
298	0.0046*
370	0.0714
471	0.1706*
573	0.2751
674	0.3818
772	0.4879
874	0.5997
973	0.7112
1076	0.8289
1175	0.9443
1276	1.0628

CURVE 4

T	$\Delta L/L_0$
373	0.079
1273	0.970

CURVE 5

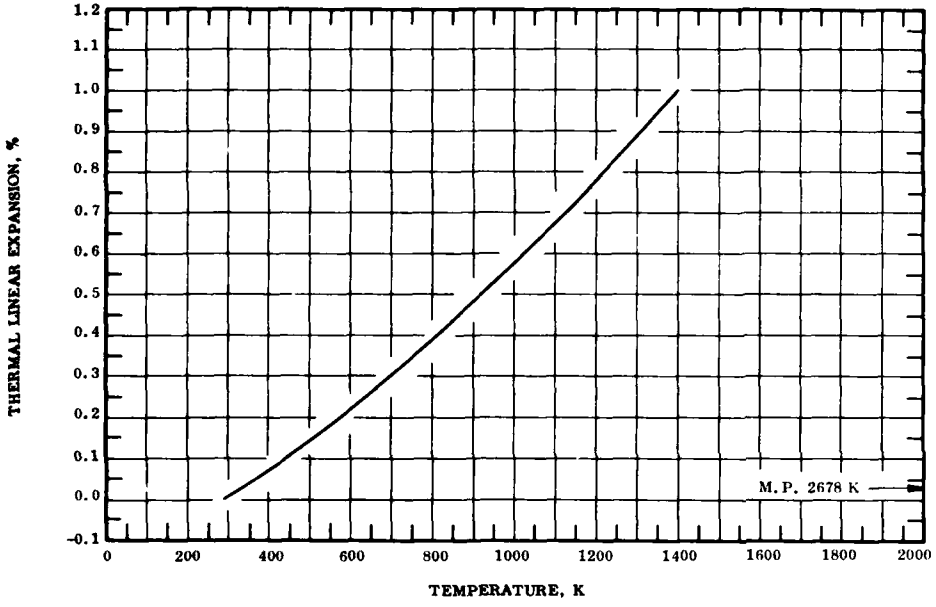
T	$\Delta L/L_0$
322	0.024
372	0.067
467	0.169
572	0.274
675	0.389
773	0.502
880	0.622
1019	0.798
1108	0.914

CURVE 6

T	$\Delta L/L_0$
273	-0.027
293	0.000*
373	0.064*
473	0.174*
573	0.265*
673	0.384*
773	0.466
873	0.558
973	0.677
1073	0.759
1173	0.869
1273	0.960
1312	0.997

* Not shown in figure.

FIGURE AND TABLE NO. 74R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SCANDIUM OXIDE Sc_2O_3



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	6.6
400	0.070	7.0
500	0.143	7.4
600	0.220	7.9
700	0.303	8.3
800	0.388	8.8
900	0.478	9.2
1000	0.573	9.7
1100	0.673	10.2
1200	0.778	10.8
1300	0.886	11.3
1400	1.004	11.9

REMARKS

The recommended values are based on the data for pure samples (curves 1 to 6) and are considered accurate to within ± 5%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.178 + 5.585 \times 10^{-4} T + 1.650 \times 10^{-7} T^2 + 2.816 \times 10^{-11} T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ± 5%.

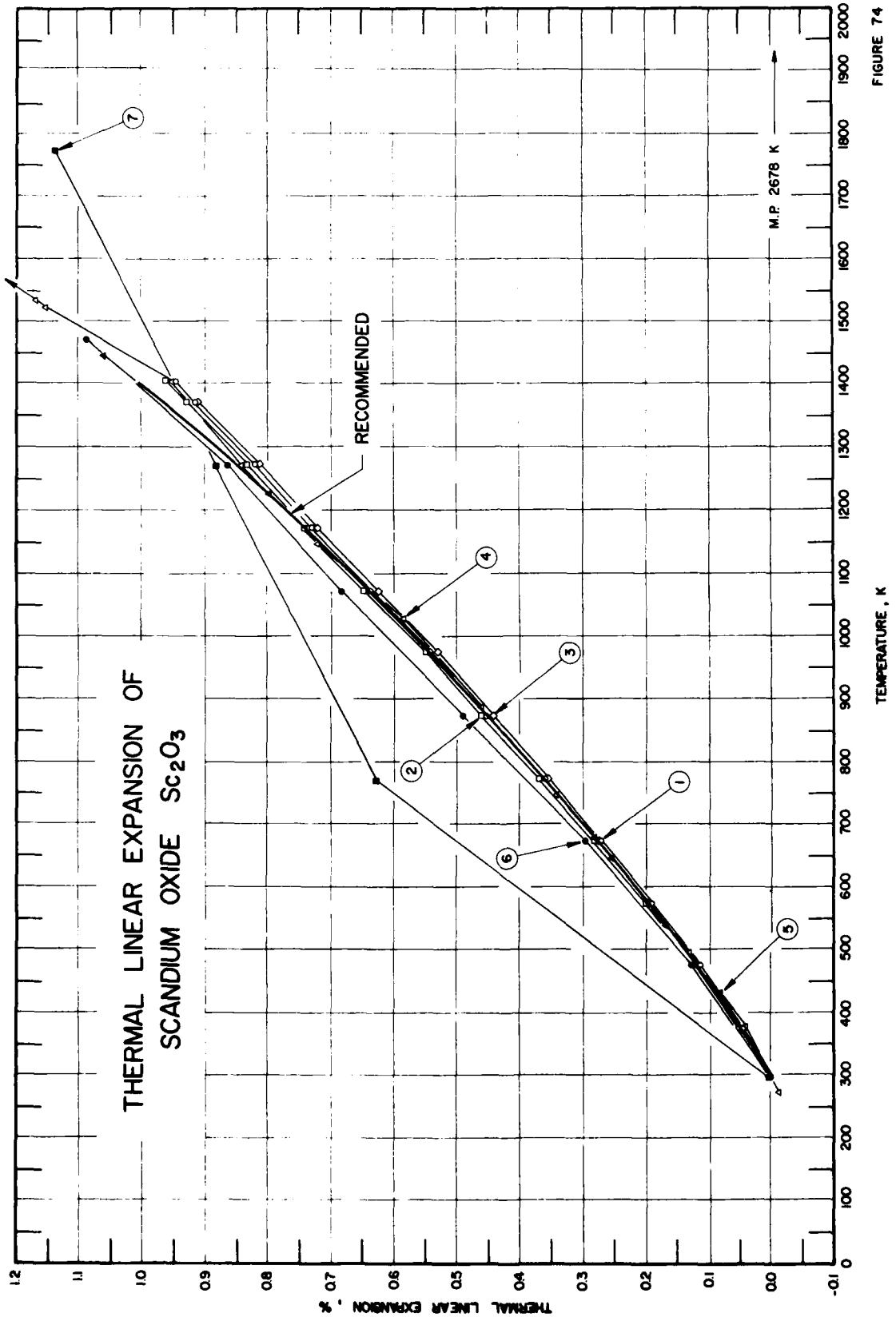

THERMAL LINEAR EXPANSION OF
SCANDIUM OXIDE Sc_2O_3
RECOMMENDED
M.P. 2678 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
4
5
6
7

FIGURE 74

SPECIFICATION TABLE 74. THERMAL LINEAR EXPANSION OF SCANDIUM OXIDE Sc_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	143	Stacy, D.W.	1967	L	298-1403	Sc_2O_3 - 1	99.9 Sc_2O_3, 0.035 Ta, 0.016 Si, 0.008 Al, ≤0.005 Er, 0.004 Ca, ≤0.003 Fe, ≤0.002 each of Cr, Cu, Lu, Ni, Ti, and Tm, ≤0.001 Mg, ≤0.001 Y, and ≤0.0005 Yb; bar specimen 0.125 x 0.24 in. cross section, 1.000±0.001 in. long; obtained from Research Chemicals Inc.; prepared by pressing powder in steel die to 1000 psi; inverted and repressed to 1200 psi, and finally pressed to 50 000 psi in isostatic press; fired at 2223 K in reducing atmosphere; 89.9% theoretical density; zero-point correction of 0.003% determined by graphical extrapolation.
2	143	Stacy, D.W.	1967	L	298-1403	Sc_2O_3 - 2	Similar to the above specimen except 89.3% theoretical density; zero-point correction of 0.003% determined by graphical extrapolation.
3	143	Stacy, D.W.	1967	L	298-1403	Sc_2O_3 - 3	Similar to the above specimen except 89.7% theoretical density; zero-point correction of 0.003% determined by graphical extrapolation.
4	68	Stecura, S. and Campbell, W.J.	1961	X	273-1573		99.5 pure; cubic type structure specimen obtained from Heavy Minerals Co.; sintered at 1423 K for 24 hr; packed into alumina holder, sintered at 1473 K, cooled to 573 K and stored in vacuum; reported error ±1%; lattice parameter reported at 273 K is 9.8428 Å; zero-point correction of -0.010% determined by graphical interpolation.
5	68	Stecura, S. and Campbell, W.J.	1961	X	1448-430		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.010% determined by graphical extrapolation.
6	99	Brown, W.R. and Kirchner, N.P.	1961	X	298-1473		99+ pure; specimen obtained from Research Chemicals, Inc.; expansion measured with Cr Kα radiation; lattice constant reported at 298 K is 9.8451 Å.
7	643	Hajek, B., Brozek, V., and Duvigneaud, P.H.	1973	L	1773-293		Thermal expansion measured with decreasing temperature; lattice parameter reported at 293 K is 9.853 Å.

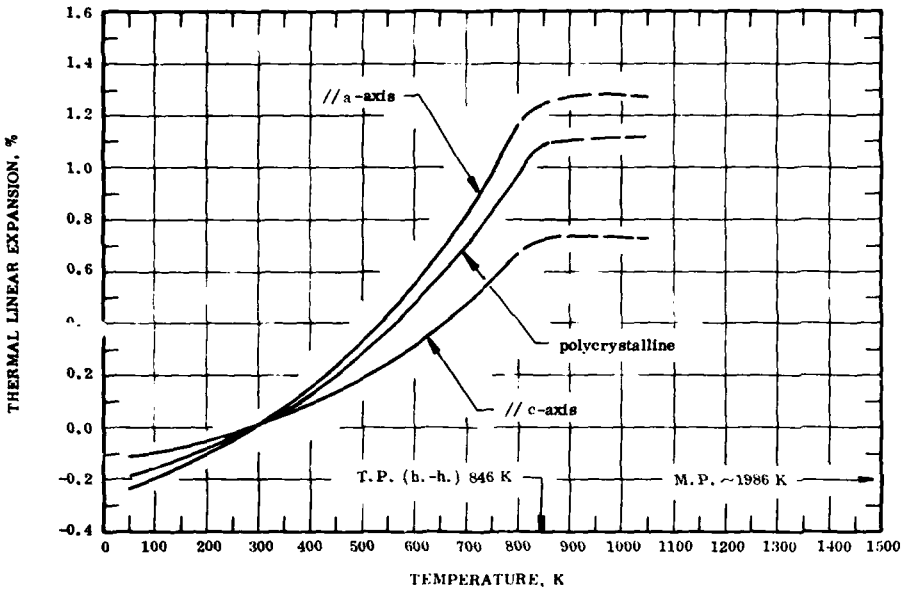
DATA TABLE 74. THERMAL LINEAR EXPANSION OF SCANDIUM OXIDE Sc_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3		CURVE 4		CURVE 5		CURVE 6 (cont.)	
298	0.003	298	0.003*	298	0.003*	273	-0.010	1448	1.062	1273	0.8644
373	0.049	373	0.051	373	0.052	296	0.002	1226	0.799	1473	1.0878
473	0.117	473	0.121	473	0.123	376	0.046	678	0.285		
573	0.193	573	0.201	573	0.198	493	0.135	539	0.172	CURVE 7	
673	0.275	673	0.285	673	0.278	648	0.256	430	0.088		
773	0.362	773	0.371	773	0.359	749	0.345			1773	1.137
873	0.456	873	0.462	873	0.443	886	0.463	CURVE 6		1273	0.883
973	0.546	973	0.554	973	0.532	1028	0.588			773	0.629
1073	0.637	1073	0.649	1073	0.624	1150	0.721	298	0.0030	293	0.000
1173	0.730	1173	0.743	1173	0.721	1272	0.842	473	0.1300		
1273	0.820	1273	0.834	1273	0.813	1403	1.004	673	0.2986		
1373	0.918	1373	0.930	1373	0.915	1523	1.153	873	0.4906		
1403	0.947	1403	0.961	1403	0.947*	1533	1.169	1073	0.6815		
						1573	1.225				

* Not shown in figure.

FIGURE AND TABLE NO. 75R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (CRYSTALLINE) SiO_2



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
50	-0.240	-0.115	-0.198	7.0
100	-0.200	-0.101	-0.166	7.3
150	-0.155	-0.080	-0.128	7.8
200	-0.110	-0.060	-0.090	8.5
250	-0.055	-0.027	-0.044	9.4
293	0.000	0.000	0.000	10.3
400	0.150	0.085	0.125	13.3
500	0.325	0.185	0.275	16.8
600	0.540	0.314	0.464	21.2
700	0.800	0.470	0.695	26.3
800	1.160	0.670	0.993	32.2
850	1.260†	0.730†	1.083†	
900	1.265†	0.730†	1.087†	
1000	1.278†	0.730†	1.095†	
1050	1.275†	0.722†	1.091†	

† Provisional values.

REMARKS

The recommended values for the axial thermal expansion are based on the data (curves 4, 6, 23 to 25 for // a-axis, curves 3, 5, 13 and 26 for // c-axis) up to transition temperature. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ± 5% at temperatures below 800 K and ± 10% above 800 K and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.290 + 8.987 \times 10^{-4}\,T - 1.690 \times 10^{-7}\,T^2 + 1.633 \times 10^{-9}\,T^3$ (50-800 K)

// c-axis: $\Delta L/L_0 = -0.136 + 3.121 \times 10^{-4}\,T + 3.174 \times 10^{-7}\,T^2 + 6.854 \times 10^{-10}\,T^3$ (50-800 K)

polycrystalline: $\Delta L/L_0 = -0.236 + 6.912 \times 10^{-4}\,T + 5.559 \times 10^{-9}\,T^2 + 1.312 \times 10^{-9}\,T^3$ (50-800 K)

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 10%.

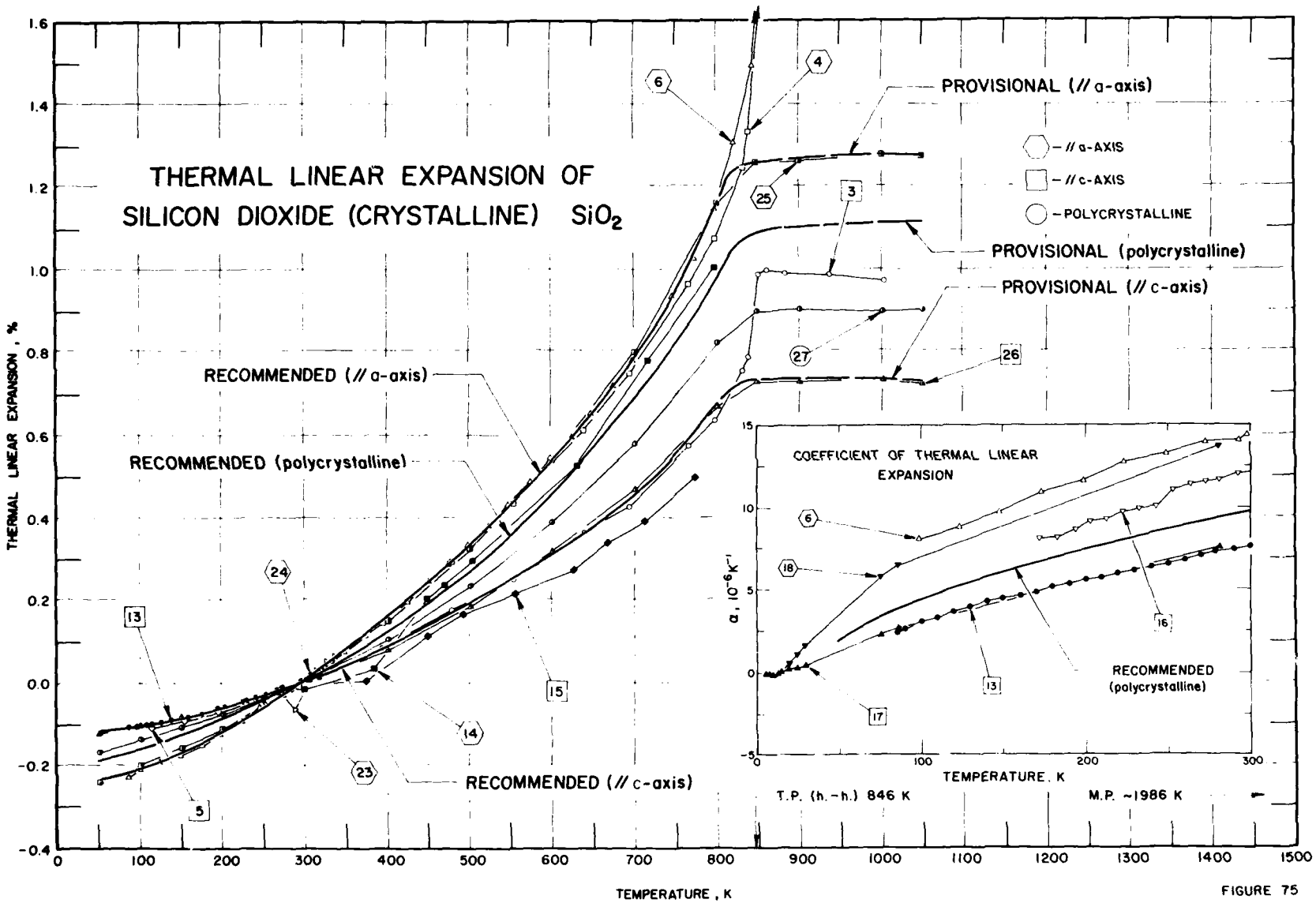

THERMAL LINEAR EXPANSION OF
SILICON DIOXIDE (CRYSTALLINE) SiO_2
PROVISIONAL (// a-axis)
// a-AXIS
// c-AXIS
POLYCRYSTALLINE
PROVISIONAL (polycrystalline)
PROVISIONAL (// c-axis)
RECOMMENDED (// a-axis)
RECOMMENDED (polycrystalline)
RECOMMENDED (// c-axis)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , $10^{-6}K^{-1}$
RECOMMENDED (polycrystalline)
T.P. (h.-h.) 846 K
M.P. ~1986 K

FIGURE 75

SPECIFICATION TABLE 75. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (CRYSTALLINE) SiO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	47	Amatuni, A.N. and Shevchenko, E.B.	1966	L	373-823	Quartz	Monocrystalline specimen; prepared by heating to 523 K, then cooling to room temperature; expansion measured perpendicular to crystallographic axis; averaged value of samples Nos. 1 and 4; length of specimens at 293 K, 9.927 mm and 9.804 mm, respectively.
2*	47	Amatuni, A.N. and Shevchenko, E.B.	1966	L	373-823	Quartz	Similar to the above specimen; expansion measured parallel to crystallographic axis; averaged value of samples Nos. 3 and 6; length of specimens at 293 K, 9.958 mm and 9.981 mm, respectively.
3	165	Jay, A.H.	1933	X	291-1003	Quartz	Powdered specimen; prepared by grinding clear, colorless crystal; expansion measured along principal axis; zero-point correction of -0.002% determined by graphical interpolation.
4	165	Jay, A.H	1933	X	291-1003	Quartz	The above specimen; expansion measured perpendicular to principal axis; zero-point correction of -0.003% determined by graphical interpolation.
5	166	Dorsey, H.G.	1908	I	113-273	Quartz	Clear specimen, 1.5264 cm long, density 2.65 g cm^{-3}; obtained from Messrs. Tiffany and Co.; cut paralell to optic axis.
6	167	Nix, F.C. and Mac Nair, D.	1941	I	84-927	Quartz	Single crystal specimen; expansion measured perpendicular to optic axis; zero-point correction of -0.028%.
7*	54	Strelkov, P.G., Lifanov, I.I., and Sherstynkov, N.G.	1966	L	361-859	Quartz Specimen 1	Monocrystalline specimen; 10 mm^2 cross section, 2-30 mm long; expansion measured along optic axis by VNIIFTRS relative quartz dilatometer.
8*	54	Strelkov, P.G., et al.	1966	L	323-852	Quartz Specimen 1	Similar to above except using VNIIM interferometer dilatometer; expansion measured along optic axis.
9*	54	Strelkov, P.G., et al	1966	L	361-835	Quartz Specimen 3	Similar to the above specimen except expansion measured perpendicular to optic axis by VNIIFTRI relative quartz dilatometer.
10*	54	Strelkov, P.G., et al.	1966	L	319-837	Quartz Specimen 3	Similar to the above except using VNIIM interferometer dilatometer; expansion measured perpendicular to optic axis.
11*	168	Rosenholtz, J.L. and Smith, D.T.	1941	L	273-1273	Quartz	Clear rock crystal; prism specimen, 4 mm square, 10 mm long; obtained from Minas Geraes, Brazil; density 2.649 g cm^{-3} at 293 K; α-β phase inversion at 573.1 ± 0.5 C; expansion measured perpendicular to principal axis.
12*	168	Rosenholtz, J.L. and Smith, D.T.	1941	L	273-1273	Quartz	Similar to the above specimen except expansion measured along principal axis.
13	169	Buffington, R.M. and Latimer, W.M.	1926	I	85-317	Quartz	Cylindrical specimen; 0.3 cm diameter, 0.400 cm long; one end plane, other ellipsoidal; cut from single crystal of 0.4 cm thick; axis of cylinders within 1 deg parallel to optic axis of crystal; zero-point correction of 0.020% determined by graphical interpolation; the thermal linear coefficient is also reported.
14	195	Kim, Y.S. and Smith, R.T.	969	X	293-796	α Quartz	Single crystal specimen; expansion measured with Fe$K\alpha$ radiation perpendicular to crystallographic axis.
15	195	Kim, Y.S. and Smith, R.T.	1969	X	293-773	α Quartz	The above specimen; expansion measured parallel to crystallographic axis.
16*	171	Asay, T.R., Urzendowski, S.R., and Guenther, A.H.	1968	L	173-473	Quartz	Standard crystal specimen; density 2.65 g cm^{-3}; authors reported expansion measured parallel to the axis (data appeared to be for polycrystalline material).
17*	196	White, G.K.	1964	E	4.0-16	Quartz	Specimen 2 cm diameter, 5 cm long; cut from large natural crystal of optical quality; expansion measured parallel to optic axis; reported error 1%; data reported using 0.0 K as reference temperature at which $\Delta L/L_0 = 0$; the thermal linear coefficient is also reported.

* Not shown in figure.

SPECIFICATION TABLE 75. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (CRYSTALLINE) SiO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
18*	196	White, G.K.	1964	E	6-283	Quartz	The above specimen; expansion measured perpendicular to optic axis.
19*	197	Snyder, N.H., Smoke, E.J., Wisely, H.R., and Ruh, E.	1950	L	301-1026	Quartz QB-32	98.0 SiO_2, 1.5 Al_2O_3, 0.5 Li_2O; specimen 6 in. long; heating rate 2-3 C per min; Zero-point correction of 0.0080% determined by graphical extrapolation.
20*	197	Snyder, N.H., et al.	1950	L	301-1021	Quartz QB-33	99.0 SiO_2, 0.8 Al_2O_3, 0.2 Li_2O; specimen 6 in. long; heating rate 2-3 C per min; zero-point correction of 0.0065% determined by graphical extrapolation.
21*	197	Snyder, N.H., et al.	1950	L	298-1003	Quartz QB-34	100.0 pure; specimen 6 in. long; heating rate 2-3 C per min; zero-point correction of 0.0050% determined by graphical extrapolation.
22*	197	Snyder, N.H., et al.	1950	L	298-993	Quartz QB-35	99.0 SiO_2, 1.0 Li_2O; specimen 6 in. long; heating rate 2-3 C per min; zero-point correction of 0.0060% determined by graphical extrapolation.
23	184	Johnson, W.H. and Parsons, W.H.	1944	I	254-337	Quartz	Single crystal specimen; obtained from Minas Geracs, Brazil; expansion measured perpendicular to c-axis.
24	184	Johnson, W.H. and Parsons, W.H.	1944	I	331-269	Quartz	Above specimen; expansion measured perpendicular to c-axis and with decreasing temperature.
25*	184	Johnson, W.H. and Parsons, W.H.	1944	I	251-337	Quartz	Similar to the above specimen; expansion measured parallel to c-axis and with increasing temperature.
26*	184	Johnson, W.H. and Parsons, W.H.	1944	I	333-265	Quartz	The above specimen; expansion measured parallel to c-axis and with decreasing temperature.
27*	266	Sweeney, W.T.	1933	I	298-874	Tridymite-Cristobalite Sample 9	Specimen 30 cm long, triangular cross-section about 2 cm on a side, fabricated by heating raw material of crystalline quartz in a gas muffle furnace above 1743 K; then it appeared to be composed of about equal amounts of tridymite and cristobalite; zero-point correction of 0.003% determined by graphical extrapolation.
28*	266	Sweeney, W.T.	1933	I	298-664	Sample 9	The above specimen; expansion measured on second test; zero-point correction of 0.006% determined by graphical extrapolation.
29*	266	Sweeney, W.T.	1933	I	298-884	Cristobalite Sample 13	Specimen 10 mm long; fabricated by heating raw material of crystalline quartz in a gas muffle furnace above 1470 C; then it appeared to be composed of about 5% quartz, and small amount of tridymite; zero-point correction of 0.004% determined by graphical extrapolation.
30*	266	Sweeney, W.T.	1933	I	297-967	Cristobalite Sample 17	Specimen 30 cm long, triangular cross-section about 2 cm on a side; fabricated by heating raw material of cryptocrystalline quartz; then it appears to be composed of about 15% quartz; zero-point correction of 0.006% determined by graphical extrapolation.
31*	266	Sweeney, W.T.	1933	I	967-302	Cristobalite Sample 17	The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.136% determined by graphical extrapolation.
32*	266	Sweeney, W.T.	1933	I	302-973	Cristobalite Sample 17	The above specimen; expansion measured with increasing temperature on second test; zero-point correction of -0.136% determined by graphical extrapolation.
33*	266	Sweeney, W.T.	1933	I	973-297	Cristobalite Sample 17	The above specimen; expansion measured with decreasing temperature on second test; zero-point correction of -0.353% determined by graphical extrapolation.

*Not shown in figure.

DATA TABLE 75. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (CRYSTALLINE) SiO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
373	0.1166
423	0.1974
473	0.2836
523	0.3758
573	0.4778
623	0.5880
673	0.7100
723	0.8508
773	1.0240
823	1.2600
CURVE 2*	
373	0.0636
423	0.1090
473	0.1590
523	0.2146
573	0.2715
623	0.3346
673	0.4090
723	0.4900
773	0.5910
823	0.7300
CURVE 3	
291	-0.002
391	0.088
476	0.172
553	0.248
639	0.360
691	0.425
767	0.570
798	0.632
831	0.750
840	0.780
852	0.982
863	0.999
883	0.994
938	0.982
1003	0.973

T	$\Delta L/L_0$
CURVE 4	
291	-0.003
391	0.145
476	0.290
553	0.436
639	0.616
691	0.743
767	0.964
798	1.077
831	1.245
840	1.332
852	1.695*
863	1.730*
883	1.730*
938	1.730*
1003	1.728*
CURVE 5	
93	-0.114
133	-0.099
173	-0.080
213	-0.057
253	-0.030
293	0.000
CURVE 6	
84	-0.228
98	-0.209
123	-0.191
148	-0.171
173	-0.147
198	-0.122
223	-0.093
248	-0.056
273	-0.028
293	0.000
298	0.009*
323	0.041
348	0.080
373	0.116
398	0.159
423	0.194
448	0.242
473	0.287

T	$\Delta L/L_0$
CURVE 6 (cont.)	
498	0.331
523	0.377
548	0.433
573	0.486
598	0.541
623	0.593
648	0.656
673	0.718
698	0.779
723	0.852
748	0.937
773	1.029
798	1.146
823	1.303
846	1.495
848	1.757*
873	1.772*
898	1.772*
923	1.772*
CURVE 7*	
361	0.069
372	0.079
386	0.091
400	0.110
415	0.123
445	0.146
457	0.155
470	0.178
484	0.193
489	0.179
517	0.233
562	0.282
582	0.300
613	0.338
620	0.342
626	0.342
629	0.344
658	0.408
685	0.457
690	0.467
717	0.491
722	0.515

T	$\Delta L/L_0$
CURVE 7 (cont.)*	
742	0.515
750	0.554
781	0.619
784	0.651
801	0.661
827	0.786
834	0.785
840	0.839
841	0.859
847	0.873
852	1.003
859	0.996
CURVE 8*	
323	0.036
330	0.042
378	0.080
426	0.126
430	0.132
475	0.169
524	0.220
543	0.243
573	0.281
575	0.291
673	0.412
677	0.421
689	0.440
725	0.506
732	0.516
771	0.597
775	0.607
799	0.669
824	0.743
850	0.881
852	0.985
CURVE 9*	
361	0.121
385	0.146
396	0.161
410	0.198
443	0.231
461	0.273

T	$\Delta L/L_0$
CURVE 9 (cont.)*	
466	0.287
504	0.328
528	0.413
536	0.419
565	0.475
578	0.498
595	0.535
597	0.556
625	0.597
633	0.630
657	0.687
668	0.694
687	0.759
690	0.771
705	0.814
709	0.842
720	0.849
740	0.928
760	0.989
772	1.044
782	1.090
786	1.101
813	1.239
818	1.274
821	1.324
826	1.348
829	1.408
832	1.474
835	1.739
CURVE 10*	
319	0.065
327	0.074
374	0.144
375	0.153
425	0.228
432	0.241
435	0.231
470	0.305
472	0.312
496	0.341
520	0.399
523	0.399
578	0.524

T	$\Delta L/L_0$
CURVE 10 (cont.)*	
581	0.524
620	0.610
622	0.616
625	0.623
670	0.743
673	0.738
724	0.882
773	1.066
776	1.066
819	1.303
821	1.299
833	1.426
835	1.482
837	1.442
CURVE 11*	
273	-0.029
373	0.115
473	0.281
573	0.471
673	0.798
773	1.010
823	1.249
846	1.447
846	1.685
873	1.713
973	1.715
1073	1.730
1173	1.728
1273	1.734
CURVE 12*	
273	-0.016
373	0.063
473	0.155
573	0.267
673	0.400
773	0.577
823	0.712
846	0.829
846	0.942
873	0.963
973	0.962

* Not shown in figure.

DATA TABLE 75. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (CRYSTALLINE) SiO_2 (continued)

T	$\Delta L/L_0$
CURVE 12 (cont.)*	
1073	0.968
1173	0.957
1273	0.926
CURVE 13	
85.2	-0.108
85.7	-0.108
95.3	-0.106
108.5	-0.102
114.9	-0.099
122.7	-0.097
123.3	-0.097
136.4	-0.092
137.8	-0.090
157.4	-0.083
174.2	-0.074
193.7	-0.064
202.1	-0.059
225.3	-0.046
229.7	-0.043
240.0	-0.036
252.4	-0.029
267.4	-0.018
271.6	-0.016
272.3	-0.015
295.0	0.002
303.8	0.008
309.2	0.012
317.9	0.019
CURVE 14	
293	0.000*
297	-0.019
381	0.033
446	0.200
469	0.237
501	0.292
630	0.524
718	0.779
796	1.003
CURVE 15	
293	0.000*
297	-0.003*
374	0.005
CURVE 15 (cont.)	
447	0.111
490	0.163
556	0.218
625	0.273
666	0.336
712	0.389
773	0.499
CURVE 16*, ‡	
173	-0.120
183	-0.112
193	-0.104
203	-0.095
213	-0.086
223	-0.076
233	-0.067
243	-0.057
253	-0.046
263	-0.035
273	-0.023
283	-0.012
293	0.000
303	0.012
313	0.024
323	0.037
333	0.050
343	0.063
353	0.076
363	0.089
373	0.103
383	0.117
393	0.131
403	0.145
413	0.159
423	0.174
433	0.188
443	0.203
453	0.218
463	0.232
473	0.247
CURVE 17*	
4.0	-0.06×10^{-6}
6.9	-0.61
7.5	-0.86
8.2	-1.19
CURVE 17 (cont.)*	
8.8	-1.58×10^{-6}
9.5	-1.96
10.1	-2.42
10.7	-2.52
11.4	-2.98
12.1	-2.98
13.0	-3.25
13.7	-2.40
14.7	-0.93
15.5	1.37
16.0	3.73
CURVE 18*	
6	-0.233
8	-0.233
10	-0.233
12	-0.233
15	-0.233
20	-0.233
25	-0.232
30	-0.232
75	-0.215
85	-0.209
283	-0.010
CURVE 19*	
301	0.0080
335	0.0386
369	0.0826
405	0.1317
434	0.1736
460	0.2190
503	0.2833
538	0.3712
579	0.519
608	0.632
651	0.720
693	0.793
726	0.853
761	0.929
798	1.020
840	1.138
871	1.324
910	1.341
948	1.345
991	1.348
1026	1.350
CURVE 20*	
301	0.0065
391	0.0982
441	0.1685
478	0.2245
512	0.2805
553	0.3665
590	0.4755
629	0.5705
660	0.6385
697	0.7285
735	0.8055
767	0.8865
803	0.9725
839	1.0865
874	1.3185
908	1.3865
937	1.3955
967	1.3975
1003	1.3985
1021	1.3985
CURVE 21*	
298	0.0050
366	0.0579
384	0.1036
427	0.1717
465	0.2543
500	0.3462
532	0.4720
563	0.5397
579	0.6085
634	0.6683
671	0.7354
710	0.8076
744	0.8843
786	0.9917
825	1.0988
853	1.2453
886	1.4471
918	1.4588
951	1.4656
1003	1.4683
CURVE 22*	
298	0.0062
329	0.0471
387	0.1701
423	0.2920
447	0.3923
478	0.6220
509	0.8836
547	1.2647
579	1.3155
621	1.3637
649	1.3932
671	1.4164
711	1.4525
739	1.4821
771	1.5119
807	1.5357
845	1.5659
871	1.5793
905	1.5930
932	1.6016
966	1.6135
993	1.6188
CURVE 23	
254	-0.049
260	-0.043
267	-0.034
274	-0.025
287	-0.067
301	0.011*
314	0.029
325	0.047
337	0.064
CURVE 24	
331	0.056
320	0.038
307	0.020
295	0.002*
280	-0.016
269	-0.031
CURVE 25*	
251	-0.028
262	-0.021
271	-0.015
286	-0.005
300	0.006
315	0.017
327	0.027
337	0.035
CURVE 26*	
333	0.032
320	0.022
307	0.012
294	0.001
280	-0.009
265	-0.020
CURVE 27*	
298	0.003
325	0.067
374	0.143
379	0.166
424	0.253
432	0.274
454	0.337
455	0.356
473	0.409
476	0.429
485	0.463
487	0.488
490	0.504
491	0.545
496	0.585
496	0.674
499	0.750
502	0.875
505	0.938
510	0.979
513	1.003
518	1.035
523	1.053
533	1.091
569	1.153
610	1.204
642	1.227
667	1.257

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 75. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (CRYSTALLINE) SiO_2 (continued)

T	$\Delta L/L_0$
CURVE 27 (cont.)*	
689	1.289
734	1.326
757	1.356
788	1.392
811	1.426
826	1.447
837	1.482
842	1.491
861	1.502
874	1.513
CURVE 28*	
298	0.006
321	0.045
367	0.127
427	0.246
437	0.280
462	0.336
473	0.377
488	0.464
491	0.488
496	0.552
499	0.578
501	0.612
502	0.642
502	0.676
504	0.719
505	0.802
507	0.854
512	0.908
532	0.972
599	1.120
664	1.170
CURVE 29*	
298	0.004
307	0.030
318	0.060
324	0.068
338	0.104
349	0.127
360	0.152
372	0.184
389	0.225
403	0.257
419	0.302
445	0.382
458	0.422
471	0.463
478	0.499
482	0.520
487	0.533
493	0.557
496	0.604
499	0.667
499	0.689
503	0.731
509	1.531
527	1.562
548	1.589
626	1.656
681	1.682
707	1.702
779	1.748
823	1.765
884	1.787
CURVE 30*	
297	0.006
376	0.149
437	0.283
447	0.312
460	0.340
469	0.366
480	0.394
493	0.437
510	0.585
510	0.685
511	0.859
511	0.874
512	0.983
514	1.046
519	1.132
524	1.159
541	1.176
573	1.195
669	1.259
812	1.369
967	1.445
CURVE 31*	
967	1.303
669	1.126
574	1.040
544	1.019
518	1.000
509	0.985
502	0.978
497	0.969
483	0.502
478	0.462
473	0.440
471	0.431
464	0.409
458	0.391
446	0.353
418	0.279
386	0.211
302	0.013
CURVE 32*	
302	0.013
386	0.211
418	0.279
446	0.353
454	0.364
470	0.395
479	0.424
489	0.459
496	0.479
501	0.516
504	0.547
507	0.582
511	0.717
511	0.732
512	0.841
513	1.058
514	1.116
518	1.175
525	1.187
542	1.206
687	1.332
973	1.483
CURVE 33*	
973	1.266
611	1.033
550	0.974
529	0.955
515	0.940
504	0.927
496	0.916
487	0.893
485	0.727
484	0.481
482	0.453
477	0.432
394	0.193
297	0.005

* Not shown in figure.

DATA TABLE 75. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (CRYSTALLINE) SiO_2

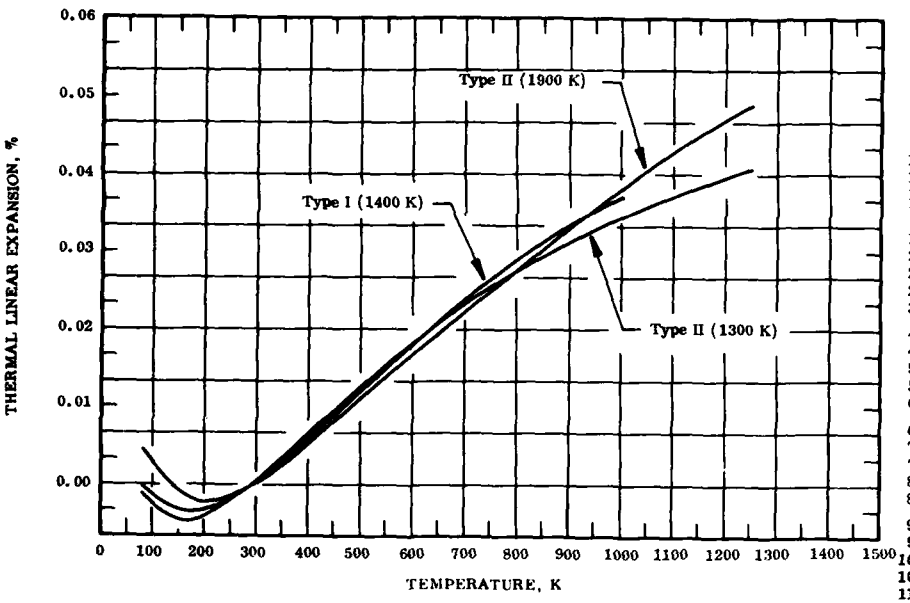
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 6	
98	8.0
123	8.7
148	9.7
173	10.9
198	11.6
223	12.7
248	13.2
273	13.9
293	14.0
298	14.4
323	15.0*
348	15.2*
373	16.0*
398	16.6*
423	16.9*
448	17.6*
473	17.9*
498	18.4*
523	19.4*
548	20.3*
573	21.0*
598	22.4*
623	23.5*
648	24.7*
673	26.5*
698	28.6*
723	31.0*
748	34.5*
773	39.7*
798	48.4*
823	66.0*
846	120.0*
848	15.0*
873	4.0*
898	1.0*
923	0.0*
CURVE 13	
85	2.40
90	2.67
100	3.05
110	3.38
120	3.69
130	3.96
140	4.20
150	4.44
160	4.66
170	4.89
180	5.11
190	5.31
200	5.53
210	5.74
220	5.95
230	6.16
240	6.37
250	6.58
260	6.79
270	7.00
280	7.22
290	7.43
300	7.64
310	7.85*
320	8.06*
CURVE 16‡	
173	8.00
183	8.07
193	8.50
203	9.01
213	9.25
223	9.55
233	9.99
243	10.05
253	11.02
263	11.43
273	11.53
283	11.66
293	12.01
303	12.11*
313	12.45*
323	12.75*
333	13.00*
343	13.01*
353	13.23*
363	13.44*
373	13.50*
383	14.04*
393	14.24*
403	14.26*
413	14.30*
CURVE 16 (cont.)	
423	14.36*
433	14.66*
443	14.75*
453	14.89*
463	14.99*
473	15.01*
CURVE 17	
6	-0.0025
8	-0.005
10	-0.006
12	0.000
15	0.030
20	0.133
25	0.305
30	0.49
75	2.25
85	2.60
283	7.50
CURVE 18	
6	0.004*
8	0.010*
10	0.027*
12	0.069*
15	0.175*
20	0.53
25	1.03
30	1.60
75	5.70
85	6.40
283	13.70

* Not shown in figure.

‡ Author's data for coefficient of expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 76R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (FUSED) SiO_2



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	Type II† (1900 K)‡ $\Delta L/L_0$	Type II† (1300 K)‡ $\Delta L/L_0$	SRM739; Type I† (1400 K)‡ $\Delta L/L_0$	SRM739; Type I† (1400 K)‡ α
80	0.0055	-0.0011	-0.0001	-0.70
100	0.0032	-0.0027	-0.0013	-0.53
120	0.0013	-0.0037	-0.0022	-0.38
140	-0.0005	-0.0044	-0.0028	-0.24
160	-0.0013	-0.0046	-0.0032	-0.10
180	-0.0020	-0.0045	-0.0032	0.02
200	-0.0020	-0.0041	-0.0031	0.13
250	-0.0016	-0.0021	-0.0018	0.35
293	0.0000	0.0000	0.0000	0.49
350	0.0028	0.0038	0.0033	0.57
400	0.0060	0.0069	0.0064	0.61
450	0.0082	0.0099	0.0094	0.63
500	0.0112	0.0129	0.0124	0.63
550	0.0138	0.0156	0.0154	0.61
600	0.0167	0.0184	0.0184	0.59
650	0.0195	0.0209	0.0213	0.56
700	0.0226	0.0233	0.0240	0.53
750	0.0251	0.0255	0.0267	0.50
800	0.0280	0.0277	0.0292	0.47
850	0.0307	0.0296	0.0315	0.44
900	0.0332	0.0313	0.0336	0.41
950	0.0359	0.0331	0.0355	0.40
1000	*0.0382*	*0.0346*	*0.0371*	*0.37*
1050	0.0405	0.0361		
1100	0.0428	0.0374		
1150	0.0450	0.0385		
1200	0.0471	0.0397		
1250	0.0492	0.0408		

REMARKS

The recommended values for the various types of fused silica are based on the data reported in NBS SRM739 by Kirby R.K. and Hahn, T.A., 1971. These values are considered accurate to within ± 3% and are represented approximately by the following equations:

Type II (1900 K): $\Delta L/L_0 = 0.022 - 2.712 \times 10^{-4} T + 9.456 \times 10^{-7} T^2 - 9.313 \times 10^{-10} T^3$ (80-293 K)

$\Delta L/L_0 = -0.014 + 4.028 \times 10^{-5} T + 2.733 \times 10^{-8} T^2 - 1.541 \times 10^{-11} T^3$ (293-1250 K)

Type II (1300 K): $\Delta L/L_0 = 0.011 - 2.303 \times 10^{-4} T + 9.968 \times 10^{-7} T^2 - 1.181 \times 10^{-9} T^3$ (80-293 K)

$\Delta L/L_0 = -0.022 + 8.728 \times 10^{-5} T - 3.200 \times 10^{-8} T^2 + 2.347 \times 10^{-12} T^3$ (293-1250 K)

Type I (1400 K): $\Delta L/L_0 = 0.008 - 1.479 \times 10^{-4} T + 5.458 \times 10^{-7} T^2 - 4.773 \times 10^{-10} T^3$ (80-293 K)

$\Delta L/L_0 = -0.015 + 3.968 \times 10^{-5} T + 4.666 \times 10^{-8} T^2 - 3.446 \times 10^{-11} T^3$ (293-1000 K)

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations *and are considered accurate to about ± 5%.*

† Type I fused silica is prepared by fusing quartz crystal powder in vacuum or low pressure inert gas atmosphere giving a material of negligible hydroxyl content.
† Type II is prepared by fusing quartz crystals in a flame giving about a 0.04 wt.% hydroxyl content.
‡ The temperature is the fictive temperature from which the glass has been quenched.

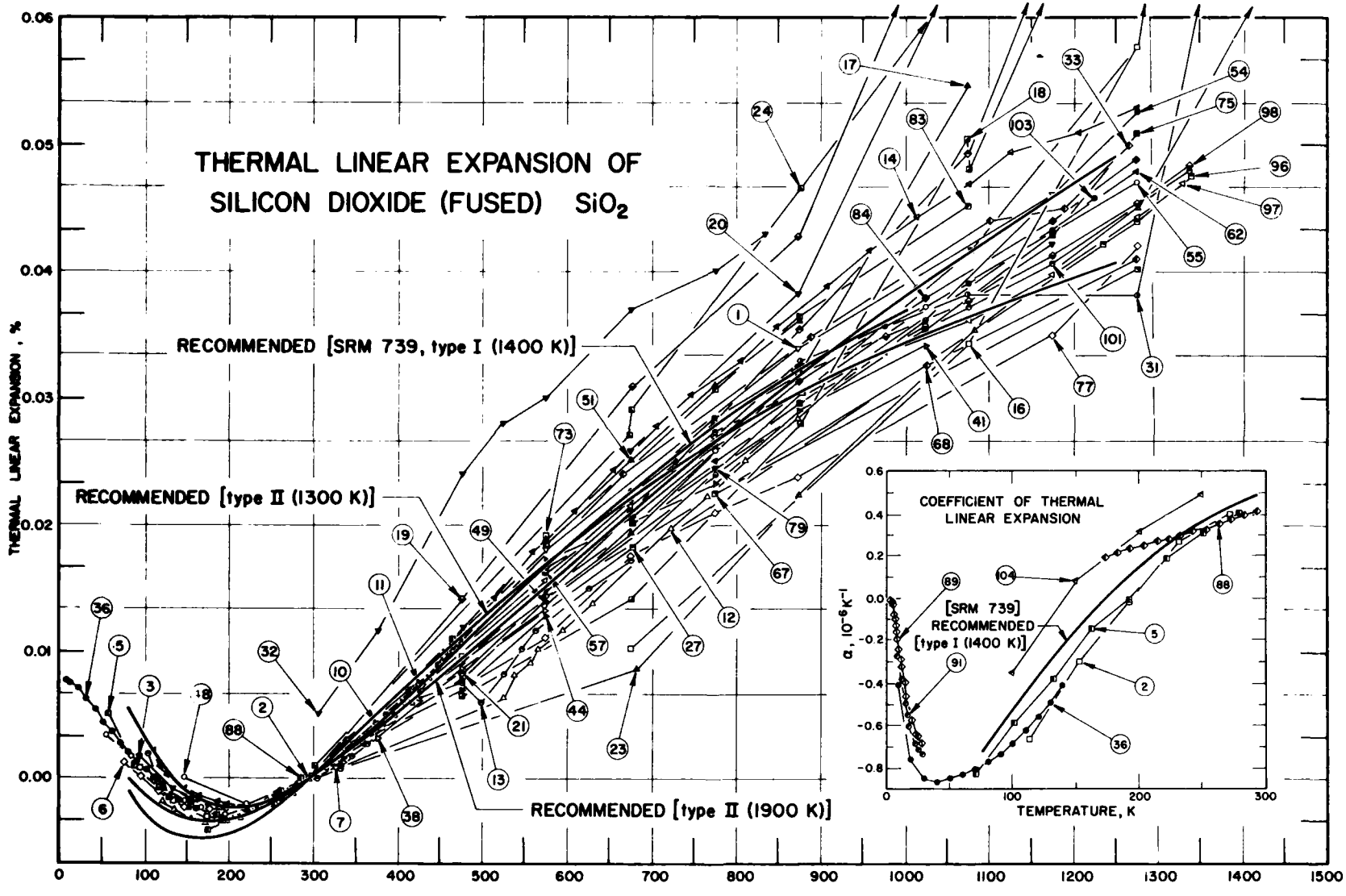

THERMAL LINEAR EXPANSION OF
SILICON DIOXIDE (FUSED) SiO_2
RECOMMENDED [SRM 739, type I (1400 K)]
RECOMMENDED [type II (1300 K)]
RECOMMENDED [type II (1900 K)]
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
[SRM 739]
RECOMMENDED
[type I (1400 K)]
α , 10^{-6} K^{-1}
TEMPERATURE, K

FIGURE 76

SPECIFICATION TABLE 76. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (FUSED) SiO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	298-1173		Specimen 0.5 x 0.5 in. cross section, 7 in. long; end sawed at rake and to point.
2	198	Dorsey, H.G.	1907	I	93-293		Specimen 1.4917 cm long; cut from tube; density 2.01 g cm^{-3}.
3	198	Dorsey, H.G.	1907	I	93-293		Transparent specimen, 1.4591 cm long; cut from mercury vapor lamp; density 2.20 g cm^{-3}.
4*	9	Sterry, W.M.	1960		353-1000	Fused silica	Commercially available specimen; data from smoothed curve.
5	199	Beattie, J.A., Blaisdell, B.E., Kaye, J., Gerry, H.T., and Johnson, C.A.	1940	L	299-57	Vitreous silica Series A1	Cylindrical specimen, 3 cm diameter, 2 cm long; expansion measured with decreasing temperature; zero-point correction of -0.00086% determined by graphical interpolation.
6	199	Beattie, J.A., et al.	1940	L	77-355	Vitreous silica Series A2	Similar to the above specimen; expansion measured with increasing temperature; zero-point correction of -0.00090% determined by graphical interpolation.
7	199	Beattie, J.A., et al.	1940	L	380-54	Vitreous silica Series A3	Similar to the above specimen; expansion measured with decreasing temperature; zero-point correction of -0.00085% determined by graphical interpolation.
8*	199	Beattie, J.A., et al.	1940	L	83-372	Vitreous silica Series A3	Similar to the above specimen; expansion measured with increasing temperature; zero-point correction of -0.00080% determined by graphical interpolation.
9*	199	Beattie, J.A., et al.	1940	L	298-373	Vitreous silica Series B1	Similar to the above specimen; zero-point correction of -0.00083% determined by graphical extrapolation.
10	199	Beattie, J.A., et al.	1940	L	373-298	Vitreous silica Series B2	Similar to the above specimen; expansion measured with decreasing temperature; zero-point correction of -0.00065% determined by graphical extrapolation.
11	199	Beattie, J.A., et al.	1940	L	323-723	Vitreous silica Series B3	Similar to the above specimen; expansion measured with increasing temperature; zero-point correction of -0.00047% determined by graphical extrapolation.
12	200	Brückner, R.	1962	I	120-939	Silica glass	Pure specimen; obtained from Fa, Heraeus; heated at 1573 K, quenched from 1573 K; zero-point correction of -0.0005% determined by graphical interpolation.
13	200	Brückner, R.	1962	I	102-673	Silica glass	Similar to the above specimen; zero-point correction of -0.0005% determined by graphical interpolation.
14	200	Brückner, R.	1962	I	110-1273		Similar to the above specimen; zero-point correction of -0.0012% determined by graphical interpolation.
15*	201	Snyder, N.H., Smoke, E.J., Wisely, H.R., Ruh, E., Bauer, H.L., Illyn, A.V., and Niemczura, S.W.	1953	L	297-973	Fused silica	No details given.
16	21	Mullineaux, J.L.	1963	R	673-1473	Fused quartz Specimen 1	Transparent rod specimen; 0.375 in. diameter, 3 ft. long; obtained from General Electric Co.; density 2.2 g cm^{-3}.
17	21	Mullineaux, J.L.	1963	R	295-1475	Fused quartz Specimen 2	Similar to the above specimen.
18	21	Mullineaux, J.L.	1963	R	1475-475	Fused quartz Specimen 2	The above specimen; expansion measured with decreasing temperature.

SPECIFICATION TABLE 76. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (FUSED) SiO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
19	21	Mullineaux, J. L.	1963	R	295-1473	Fused quartz Specimen 2	The above specimen; expansion measured with increasing temperature; second test.
20	21	Mullineaux, J. L.	1963	R	1473-295	Fused quartz Specimen 2	The above specimen; expansion measured with decreasing temperature on second test; zero-point correction of 0.0034% determined by graphical extrapolation.
21	21	Mullineaux, J. L.	1963	R	473-1466	Fused quartz	GE transparent, similar to the above specimen; expansion measured with increasing temperature before thermal cycling; zero-point correction of -0.0008% determined by graphical extrapolation.
22*	21	Mullineaux, J. L.	1963	R	473-1466	Fused quartz	The above specimen; subject to 10 cycles of rapid heating to 1255 K and rapid cooling to room temperature; zero-point correction of -0.0010% determined by graphical extrapolation.
23	21	Mullineaux, J. L.	1963	R	300-1473	Fused quartz Specimen 1	Vitreosil translucent specimen; 0.375 in. diameter, 3 ft. long; obtained from Thermal American Fused Quartz Co.; density 2.07-2.15 g cm^{-3}; zero-point correction of 0.0005% determined by graphical extrapolation.
24	21	Mullineaux, J. L.	1963	R	300-1473	Fused quartz Specimen 2	Similar to the above specimen; zero-point correction of 0.0010% determined by graphical extrapolation.
25*	21	Mullineaux, J. L.	1963	R	1473-300	Fused quartz Specimen 2	The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.009% determined by graphical extrapolation.
26*	21	Mullineaux, J. L.	1963	R	300-1473	Fused quartz Specimen 2	The above specimen; expansion measured with increasing temperature on second test; zero-point correction of 0.0003% determined by graphical extrapolation.
27	21	Mullineaux, J. L.	1963	R	1473-300	Fused quartz Specimen 2	The above specimen; expansion measured with decreasing temperature on second test; zero-point correction of 0.0005% determined by graphical extrapolation.
28*	21	Mullineaux, J. L.	1963	R	300-1473	Fused quartz Specimen 2	The above specimen; expansion measured with increasing temperature on third test; zero-point correction of 0.0004% determined by graphical extrapolation.
29*	21	Mullineaux, J. L.	1963	R	1473-300	Fused quartz Specimen 2	The above specimen; expansion measured with decreasing temperature on third test; zero-point correction of 0.0043% determined by graphical extrapolation.
30*	21	Mullineaux, J. L.	1963	R	478-1470	Fused quartz	Similar to the above specimen; expansion measured before thermal cycling; zero-point correction of -0.0016% determined by graphical extrapolation.
31	21	Mullineaux, J. L.	1963	R	473-1470	Fused quartz	The above specimen; subjected to 10 cycles of rapid heating to 1255 K and rapid cooling to room temperature; zero-point correction of -0.0010% determined by graphical extrapolation.
32	202	Hallse, R. L., Colburn, S. C., and Beck, A. P.	1965	I	305-831	Fused silica	Ball specimen; milled and fired at 1503 K; zero-point correction of 0.005% determined by graphical extrapolation.
33	28	Merritt, G. E.	1926	I	339-1265		Specimen prepared by fusing clear crystalline quartz at General Electric Co.; zero-point correction of -0.005% determined by graphical extrapolation.
34*	206	Souder, W., Hidnert, P., and Fox, J. F.	1934	O	293-1023	Sample 1057B	Specimen 12 mm diameter, 150 mm long; pointed ends; annealed; expansion measured on first test; reported error 12%.
35*	206	Souder, W., et al.	1934	O	293-1023	Sample 1057B	The above specimen; expansion measured with decreasing temperature on first test; reported error 12%.

* Not shown in figure.

SPECIFICATION TABLE 76. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (FUSED) SiO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
36	204	Gibbons, D. F.	1959	I	5-300	Vitreous silica	Specimen ground from optical-quality vitreous silica; obtained from Amersil Co.; annealed at 1073 K to remove internal stress before measurement; zero-point correction of -0.00091% determined by graphical interpolation; coefficient of thermal linear expansion also reported.
37*	205	Souder, W. and Hidnert, P.	1926	I	148-293	Transparent Fused silica 1056A	Pure SiO_2, < 0.1 alumina or lime; specimen 8 mm diameter, 300 mm long; obtained from Thermal Syndicate Ltd., Brooklyn, N. Y.; heated to 1273 K for 4 hr, cooled overnight to 1073 K, then heated to 1273 K and cooled overnight to 1073 K and slowly to 923 K; reported error 0.1%.
38	205	Souder, W. and Hidnert, P.	1926	I	293-573	Transparent Fused silica 1056A	The above specimen; expansion measured after heat treatment and low temperature test; reported error 0.1%.
39*	205	Souder, W. and Hidnert, P.	1926	I	293-573	Transparent Fused silica 1056A	Similar to the above specimen; expansion measured on first test; reported error 0.1%.
40*	205	Souder, W. and Hidnert, P.	1926	I	293-573	Transparent Fused silica 1056A	The above specimen; expansion measured on second test.
41	205	Souder, W. and Hidnert, P.	1926	I	293-1023	Fused silica 1056	Specimen cut from the same rod as the above specimen; reported error 0.1%.
42*	205	Souder, W. and Hidnert, P.	1926	I	148-293	Fused silica 1057	Similar to the above specimen except rod specimen, 6 mm diameter; annealed at Thermal Syndicate Ltd.; reported error 0.1%.
43*	205	Souder, W. and Hidnert, P.	1926	I	293-573	Fused silica 1057	The above specimen; expansion measured after low temperature test; reported error 0.1%.
44	205	Souder, W. and Hidnert, P.	1926	I	293-573	Fused silica 1057A	Specimen cut from the same rod as the above specimen; reported error 0.1%.
45*	205	Souder, W. and Hidnert, P.	1926	I	293-573	Fused silica 1057A	The above specimen; expansion measured on second test; reported error 0.1%.
46*	205	Souder, W. and Hidnert, P.	1926	I	1273-293	Fused silica 1057A	The above specimen; expansion measured with decreasing temperature on third test; reported error 0.1%.
47*	205	Souder, W. and Hidnert, P.	1926	I	293-1273	Fused silica 1057A	The above specimen; expansion measured with increasing temperature on fourth test; reported error 0.1%.
48	205	Souder, W. and Hidnert, P.	1926	I	148-293	Fused silica 1102B	Specimen 5 mm diameter, 30 mm long; obtained from General Electric Co., Schenectady, N. Y.; prepared by fusing 100% water-clear crystal quartz; expansion measured on second test; reported error 0.1%.
49	205	Souder, W. and Hidnert, P.	1926	I	293-573	Fused silica 1102B	The above specimen; expansion measured on second test; reported error 0.1%.
50*	205	Souder, W. and Hidnert, P.	1926	I	293-573	Fused silica 1102B	The above specimen; expansion measured in oil bath on third test; reported error 0.1%.

SPECIFICATION TABLE 76. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (FUSED) SiO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
51	205	Souder, W. and Hidnert, P.	1926	I	293-873	Fused silica 1102	Similar to the above specimen except 7 mm diameter; reported error 0.1%.
52*	205	Souder, W. and Hidnert, P.	1926	I	1273-273	Fused silica 1102	The above specimen; expansion measured with decreasing temperature; reported error 0.1%.
53*	205	Souder, W. and Hidnert, P.	1926	I	293-1273	Fused silica 1102	The above specimen; expansion measured with increasing temperature on second test; reported error 0.1%.
54	205	Souder, W. and Hidnert, P.	1926	I	1273-293	Fused silica 1102A	Similar to the above specimen; expansion measured with decreasing temperature after heat treatment on first test; reported error 0.1%.
55	205	Souder, W. and Hidnert, P.	1926	I	293-1273	Fused silica 1102A	The above specimen; expansion measured with increasing temperature on second test; reported error 0.1%.
56*	205	Souder, W. and Hidnert, P.	1926	I	293-573	Fused silica 56	Heraeus patented rod specimen; 8 mm diameter; obtained from Charles Engelhard, New York, N.Y.; prepared from transparent, water-clear, Brazilian rock crystal; expansion measured in oil bath; reported error 0.1%.
57	205	Souder, W. and Hidnert, P.	1926	I	293-1023	Fused silica 56	The above specimen; expansion measured after heat treatment on second test; reported error 0.1%.
58*	205	Souder, W. and Hidnert, P.	1926	I	1273-293	Fused silica 56	The above specimen; expansion measured with decreasing temperature on second test; reported error 0.1%.
59*	205	Souder, W. and Hidnert, P.	1926	I	293-1023	Fused silica 56	The above specimen; expansion measured with increasing temperature on third test; reported error 0.1%.
60*	205	Souder, W. and Hidnert, P.	1926	I	293-573	Fused silica 58	99.8 pure; semiopaque rod specimen, 9 mm diameter; grayish color; obtained from Thermal Syndicate, Ltd., Brooklyn, N.Y.; annealed at 1100 C 1 hr; expansion measured on first test; reported error 0.1%.
61*	205	Souder, W. and Hidnert, P.	1926	I	293-1023	Fused silica 58	The above specimen; expansion measured on second test; reported error 0.1%.
62	205	Souder, W. and Hidnert, P.	1926	I	1273-293	Fused silica 58	The above specimen; expansion measured with decreasing temperature on second test; reported error 0.1%.
63*	205	Souder, W. and Hidnert, P.	1926	I	293-1273	Fused silica 58	The above specimen; expansion measured with increasing temperature on third test; reported error 0.1%.
64*	205	Souder, W. and Hidnert, P.	1926	I	293-573	Fused silica 60	99.8 pure; rod specimen 7 x 7 mm cross section; grayish color; obtained from Thermal Syndicate Ltd., Brooklyn, N.Y.; prepared by fusing silica round central rod and blowing into mold; annealed at 1100 C for 1 hr; expansion measured in oil bath; reported error 0.1%.
65*	205	Souder, W. and Hidnert, P.	1926	I	293-573	Fused silica 60	The above specimen; expansion measured on second test; reported error 0.1%.
66*	205	Souder, W. and Hidnert, P.	1926	I	293-773	Fused silica 60	The above specimen; expansion measured after heat treatment on third test; reported error 0.1%.
67	205	Souder, W. and Hidnert, P.	1926	I	1273-293	Fused silica 60	The above specimen; expansion measured with decreasing temperature on third test; reported error 0.1%.

SPECIFICATION TABLE 76. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (FUSED) SiO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
68	205	Souder, W. and Hidnert, P.	1926	I	293-1273	Fused silica 60	The above specimen; expansion measured with increasing temperature on fourth test; reported error 0.1%.
69*	205	Souder, W. and Hidnert, P.	1926	I	293-473	Fused silica 63	Semiopaque rod specimen, 7 mm diameter; grayish color; expansion measured on first test; reported error 0.1%.
70*	205	Souder, W. and Hidnert, P.	1926	I	293-373	Fused silica 63	The above specimen; expansion measured on second test; reported error 0.1%.
71*	205	Souder, W. and Hidnert, P.	1926	I	293-573	Fused silica 63	The above specimen; expansion measured on third test; reported error 0.1%.
72*	205	Souder, W. and Hidnert, P.	1926	I	293-473	Fused silica 71	Opaque rod specimen; 7 x 8 mm cross section; milky white; not annealed; expansion measured on first test; reported error 0.1%.
73	205	Souder, W. and Hidnert, P.	1926	I	293-573	Fused silica 71	The above specimen; expansion measured on second test; reported error 0.1%.
74*	205	Souder, W. and Hidnert, P.	1926	I	293-873	Fused silica 76	Translucent glazed half tube specimen; 20 mm I.D., 3 mm wall thickness; obtained from Thermal Syndicate, Ltd., Brooklyn, N.Y.; expansion measured on first test; reported error 0.1%.
75	205	Souder, W. and Hidnert, P.	1926	I	293-1273	Fused silica 76	The above specimen; expansion measured on second test; reported error 0.1%.
76*	205	Souder, W. and Hidnert, P.	1926	I	293, 573	Fused silica 80	Similar to the above specimen; annealed at 1423 K; expansion measured on first test; reported error 0.1%.
77	205	Souder, W. and Hidnert, P.	1926	I	293-1273	Fused silica 80	The above specimen; expansion measured on second test; reported error 0.1%.
78*	205	Souder, W. and Hidnert, P.	1926	I	293-773	Fused silica 1060	Transparent half-tube specimen; 20 mm I.D., 2 mm wall thickness; obtained from Thermal Syndicate Ltd., Brooklyn, N.Y.; heated to 1273 K for 4 hr, cooled overnight to 1073 K then heated to 1273 K for 2 hr, cooled overnight to 1073 K then slowly to 923 K; annealed; expansion measured on first test; reported error 0.1%.
79	205	Souder, and Hidnert, P.	1926	I	1173-293	Fused silica 1060	The above specimen; expansion measured with decreasing temperature on first test; reported error 0.1%.
80*	205	Souder, W. and Hidnert, P.	1926	I	293-1023	Fused silica 1060	The above specimen; expansion measured with increasing temperature on second test; reported error 0.1%.
81*	205	Souder, W. and Hidnert, P.	1926	I	293-773	Fused silica 1060	The above specimen; expansion measured on third test; reported error 0.1%.
82*	205	Souder, W. and Hidnert, P.	1926	I	293-1273	Fused silica 1060A	Specimen cut from the same half-tube as the above specimen; expansion measured after heat treatment on first test; reported error 0.1%.
83	205	Souder, W. and Hidnert, P.	1926	I	293-1073	Fused silica 1061A	Similar to the above specimen; expansion measured on first test; reported error 0.1%.
84	205	Souder, W. and Hidnert, P.	1926	I	293-1273	Fused silica 1061A	The above specimen; expansion measured on second test; reported error 0.1%.

* Not shown in figure.

SPECIFICATION TABLE 76. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (FUSED) SiO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
85*	203	Plummer, W.A. and Hagy, H.E.	1968	L	277-327	Cornings' Code 7971 Vitreous silica	Specimen 10 cm long; obtained from Corning Glass Works, Corning, N.Y.; zero-point correction of 0.00002% determined by graphical interpolation.
86*	203	Plummer, W.A. and Hagy, H.E.	1968	L	318-298	Cornings' Code 7971 Vitreous silica	The above specimen; expansion measured with decreasing temperature.
87*	203	Plummer, W.A. and Hagy, H.E.	1968	I	268-328	Cornings' Code 7940 Vitreous silica	Specimen 1.27 cm I.D., 1.9 cm O.D., 10 cm long; obtained from Corning Glass Works; heated at 1323 K for 6 hr; zero-point correction of -0.0009%.
88	171	Asay, J.R., Urzendowski, S.R., and Guenther, A.H.	1968	L	173-473		Specimen prepared by fusing rock crystal quartz in electric furnace above 1983 K; density 1.93 g cm^{-3}; reported values below 273 K were extrapolated by authors.
89*	208	White, G.K. and Birch, J.A.	1965	E	2.1-7.5	Spectrosil	0.1 hydroxyl, < 0.0001 metallic impurities; synthetic cylindrical specimen, 2 cm diameter, 5 cm long; obtained from Thermal Syndicate Ltd, Wallsend, Northumberland; fictive temperature 1273 K; density 2.2000 g cm^{-3} at 293 K; reported error 1%; data reported using 2.0 K as reference temperature at which $\Delta L/L_0 = 0$; coefficient of thermal linear expansion also reported.
90*	208	White, G.K. and Birch, J.A.	1965	E	4.1-7.5	Spectrosil	Similar to the above specimen; fictive temperature 1323 K; reported error 1%; data reported using 2.0 K as reference temperature at which $\Delta L/L_0 = 0$.
91*	208	White, G.K. and Birch, J.A.	1965	E	1.9-7.6		Similar to the above specimen; fictive temperature 1050 C, received neutron flux 5.1 x 10^{19} nvt; density 2.2532 g cm^{-3} at 293 K; reported error 1%; data reported using 2.0 K as reference temperature at which $\Delta L/L_0 = 0$; coefficient of thermal linear expansion also reported.
92*	208	White, G.K. and Birch, J.A.	1965	E	2.9-9.9	Spectrosil	Similar to the above specimen; fictive temperature 1323 K, received neutron flux 5.1 x 10^{19} nvt; density 2.2532 g cm^{-3} at 293 K; reported error 1%; data reported using 2.0 K as reference temperature at which $\Delta L/L_0 = 0$; coefficient of thermal linear expansion also reported.
93*	208	White, G.K. and Birch, J.A.	1965	E	2.2-7.2	I.R. Vitreosil	Similar to the above specimen except higher content of metallic impurities, very low hydroxyl content; prepared by electrical fusing of quartz powder; fictive temperature 1000 C; density 2.2016 g cm^{-3} at 293 K; reported error 1%; data reported using 2.0 K as reference temperature at which $\Delta L/L_0 = 0$; coefficient of thermal linear expansion also reported.
94*	208	White, G.K. and Birch, J.A.	1965	E	2.2-7.4	I.R. Vitreosil	Similar to the above specimen; fictive temperature 1673 K; density 2.2030 g cm^{-3} at 293 K; reported error 1%; data reported using 2.0 K as reference temperature at which $\Delta L/L_0 = 0$; coefficient of thermal linear expansion also reported.
95*	196	White, G.K.	1964	E	1.8-18	Spectrosil B	0.1 hydroxyl, < 0.0001 other impurities; synthetic cylindrical specimen 2 cm diameter, 5 cm long; obtained from Thermal Syndicate Ltd, Northumberland, England; prepared from silicon compound by hydrolysis or oxidation; reported error 1%; data reported using 2.0 K as reference temperature at which $\Delta L/L_0 = 0$; coefficient of thermal linear expansion also reported.
96	209	Oishi, J. and Kimura, T.	1969	T	288-1338	Type II T-1.0 A	Tublar specimen, 8 mm O.D., 0.5-1.0 mm wall thickness, 40 cm long; obtained from Toshibar Ceramics, Ltd, Japan; prepared by fusing of quartz crystal in flame.

* Not shown in figure.

SPECIFICATION TABLE 76. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (FUSED) SiO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
97	209	Oishi, J. and Kimura, T.	1969	T	288-1329	Type II T-1.0 B	Similar to the above specimen.
98	209	Oishi, J. and Kimura, T.	1969	T	288-1333	Type II K-1.0	Similar to the above specimen; obtained from Kimmon Manufacturing Ltd, Japan.
99*	209	Oishi, J. and Kimura, T.	1969	T	288-1333	Type II N-1.0	Similar to the above specimen; obtained from Nippon Sekiei Garasu Ltd, Japan.
100*	209	Oishi, J. and Kimura, T.	1969	T	288-1338	Type II TS(066)-0.5A Vitreosil 066	Similar to the above specimen; obtained from Thermal Syndicate Ltd, England.
101	209	Oishi, J. and Kimura, T.	1969	T	288-1334	Type II TS(066)-0.5B Vitreosil 066	Similar to the above specimen.
102*	209	Oishi, J. and Kimura, T.	1969	T	288-1330	Type I Normal quality Vitreosil	Similar to the above specimen; prepared by electric melting of quartz crystal powder in vacuum or in inert gas at low pressure.
103	209	Oishi, J. and Kimura, T.	1969	T	288-1223	Type III Spectrosil	Similar to the above specimen; prepared by vapor phase hydrolysis of pure silicon tetrachloride.

*Not shown in figure.

DATA TABLE 76. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (FUSED) SiO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.00034
573	0.018
873	0.034
1173	0.046
CURVE 2	
93	0.0008
133	-0.0018
173	-0.0030
213	-0.0030
253	-0.0018
293	0.0000
CURVE 3	
93	0.0018
133	-0.0009
173	-0.0021
213	-0.0023
253	-0.0014
293	0.0000*
CURVE 4*	
353	0.009
366	0.009
477	0.014
589	0.018
700	0.024
811	0.029
922	0.033
1000	0.036
CURVE 5	
299.29	0.000307*
264.50	-0.00122
232.55	-0.00212
185.10	-0.00264
155.52	-0.00222
130.22	-0.00161
86.73	0.000829
57.14	0.00502

T	$\Delta L/L_0$
CURVE 6	
77.54	0.00134
95.34	0.000119
117.27	-0.00101
147.48	-0.00232
176.12	-0.00253
196.78	-0.00259
217.16	-0.00246
244.33	-0.00188
269.13	-0.00108
296.78	0.000147*
326.42	0.00159
355.50	0.00309
CURVE 7	
380.60	0.00466
356.10	0.00318*
326.70	0.00144
261.85	-0.00116*
192.58	-0.00274
167.60	-0.00243
145.93	-0.00195
116.06	-0.000909
83.87	0.00119
54.66	0.00347
CURVE 8*	
83.13	0.00125
104.82	-0.00140
141.03	-0.00178
170.74	-0.00238
193.59	-0.00272
207.76	-0.00254
208.93	-0.00242
262.73	-0.00125
285.85	-0.000309
287.10	-0.000196
319.00	0.00129
372.43	0.00422
CURVE 9*	
298	0.000227
323	0.00149

T	$\Delta L/L_0$
CURVE 9 (cont.)*	
345	0.00278
373	0.00411
CURVE 10	
373	0.00440
348	0.00298
323	0.00164
298	0.000283*
CURVE 11	
323	0.00167*
423	0.00756
523	0.0139
623	0.0199
723	0.0251
CURVE 12	
120	-0.0018
135	-0.0026
151	-0.0033
170	-0.0035
188	-0.0033
204	-0.0030
223	-0.0024
245	-0.0017*
524	0.0065
539	0.0082
558	0.0092
568	0.0101
594	0.0117
630	0.0138
721	0.0198
767	0.0224
810	0.0255
873	0.0285
939	0.0324
CURVE 13	
102	0.0020
114	-0.0001
151	-0.0017

T	$\Delta L/L_0$
CURVE 13 (cont.)	
170	-0.0021*
186	-0.0023
301	0.0000
330	0.0009
344	0.0018
362	0.0027
422	0.0064
472	0.0074
496	0.0060
525	0.0083
547	0.0104
564	0.0116
621	0.0149
673	0.0171
CURVE 14	
110	0.0023
125	0.0004
147	-0.0008
163	-0.0015
185	-0.0019
199	-0.0021
214	-0.0021*
259	-0.0015
301	0.0000*
358	0.0032
410	0.0070
462	0.0105
513	0.0143
560	0.0178
609	0.0212
654	0.0245
704	0.0277
747	0.0305
801	0.0333
849	0.0358
905	0.0386
957	0.0417
1012	0.0444
1073	0.0469
1125	0.0494
1208	0.0515
1273	0.0529

T	$\Delta L/L_0$
CURVE 15*	
297	0.0000
373	0.0040
473	0.0095
573	0.0149
673	0.0204
773	0.0259
873	0.0313
973	0.0368
CURVE 16	
673	0.0102
1073	0.0345
1273	0.0579
1473	0.1394*
CURVE 17	
295	0.0000*
673	0.0194
875	0.0322
1073	0.0548
1273	0.0834*
1475	0.1069*
CURVE 18	
1475	0.1069*
1273	0.0792*
1073	0.0481
1071	0.0506
874	0.0280
673	0.0141
475	0.0066
CURVE 19	
295	0.0000*
473	0.0141
673	0.0309
873	0.0428
1273	0.1031*
1473	0.1269*

T	$\Delta L/L_0$
CURVE 20	
1473	0.1303*
873	0.0382
673	0.0258
473	0.0119
295	0.0000*
CURVE 21	
473	0.0083
673	0.0210
873	0.0355
1073	0.0494
1273	0.0941*
1466	0.1243*
CURVE 22*	
473	0.0069
673	0.0079
873	0.0122
1073	0.0211
1273	0.0691
1466	0.0879
CURVE 23	
300	0.0005
680	0.0087
873	0.0225
1080	0.0355
1273	0.0451
1473	0.0675*
CURVE 24	
300	0.0010
673	0.0271
675	0.0289
876	0.0466
1075	0.0642*
1280	0.0843*
1473	0.1043*

*Not shown in figure.

DATA TABLE 76. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (FUSED) SiO_2 (continued)

T	$\Delta L/L_0$
CURVE 25*	
1473	0.0943
1280	0.0816
1073	0.0588
873	0.0402
675	0.0271
300	0.0007
CURVE 26*	
300	0.0003
676	0.0116
1078	0.0381
1273	0.0535
1473	0.0713
CURVE 27	
1473	0.0715*
1273	0.0578*
1078	0.0419
876	0.0305
676	0.0181
300	0.0005*
CURVE 28*	
300	0.0004
673	0.0217
878	0.0375
1074	0.0601
1273	0.0794
1473	0.1016
CURVE 29*	
1473	0.1055
1273	0.0788
1073	0.0582
875	0.0377
873	0.0361
673	0.0189
300	0.0003
CURVE 30*	
478	0.0142
671	0.0347

T	$\Delta L/L_0$
CURVE 30 (cont.)*	
874	0.0473
1070	0.0612
1273	0.0768
1470	0.1005
CURVE 31	
473	0.0092
673	0.0209*
873	0.0328
1071	0.0384
1273	0.0384
1470	0.0997*
CURVE 32	
305	0.005
372	0.014
473	0.024
523	0.028
574	0.030
673	0.037
774	0.040
831	0.043
CURVE 33	
339	0.003
473	0.011
664	0.024
888	0.035
1100	0.044
1189	0.045
1265	0.050
CURVE 34*	
293	0.000
573	0.028
773	0.000
1023	0.007
CURVE 35*	
293	0.000
573	0.020
773	0.024
1023	0.029

T	$\Delta L/L_0$
CURVE 36	
5	0.00784
10	0.00771
20	0.00706
30	0.00628
40	0.00539
50	0.00456
60	0.00373
70	0.00289
80	0.00211
90	0.00133
100	0.00063
110	-0.00008
120	-0.00062
130	-0.00117*
140	-0.00167
160	-0.00234
190	-0.00271
220	-0.00246
260	-0.00150
300	0.00044*
CURVE 37*	
148	-0.0013
176	-0.0014
293	0.0000
CURVE 38	
293	0.0000*
333	0.0013
373	0.0032
473	0.0086
573	0.0132
CURVE 39*	
293	0.0000
333	0.0011
373	0.0031
473	0.0095
573	0.0154
CURVE 40*	
293	0.0000
333	0.0019
373	0.0040

T	$\Delta L/L_0$
CURVE 40 (cont.)*	
473	0.0094
573	0.0148
CURVE 41	
293	0.0000*
573	0.0171
673	0.0217*
773	0.0235
873	0.0290
1023	0.0343
CURVE 42*	
148	-0.0016
194	-0.0021
293	0.0000
CURVE 43*	
293	0.0000
333	0.0011
373	*0.0034*
473	0.0088
573	0.0165
CURVE 44	
293	0.0000*
333	0.0017
373	0.0038
473	0.0068
573	0.0129
CURVE 45*	
293	0.0000
333	0.0025
373	0.0046
473	0.0086
573	0.0154
CURVE 46*	
1273	0.0451
773	0.0230
293	0.0000

T	$\Delta L/L_0$
CURVE 47*	
293	0.0000
573	0.0129
773	0.0235
1020	0.0343
1273	0.0441
CURVE 48	
148	0.0000
220	-0.0021
293	0.0000*
CURVE 49	
293	0.0000*
333	0.0021
373	0.0041*
473	0.0079
573	0.0140
CURVE 50*	
293	0.0000
333	0.0013
373	0.0034
473	0.0088
573	0.0140
CURVE 51	
293	0.0000*
573	0.0188
673	0.0251
773	0.0312
873	0.0365
CURVE 52*	
1273	0.0509
573	0.0151
293	0.0000
CURVE 53*	
293	0.0000
573	0.0154
673	0.0217

T	$\Delta L/L_0$
CURVE 53 (cont.)*	
773	0.0274
873	0.0325
1023	0.0394
1173	0.0466
1273	0.0509
CURVE 54	
1273	0.0529
1023	0.0365
773	0.0240
573	0.0140*
293	0.0000*
CURVE 55	
293	0.0000*
573	0.0137
773	0.0259
1023	0.0372
1273	0.0470
CURVE 56*	
293	0.0000
333	0.0013
373	0.0029
473	0.0094
573	0.0143
CURVE 57	
293	0.0000*
573	0.0162
773	0.0264
1023	0.0358
CURVE 58*	
1273	0.0480
773	0.0235
573	0.0132
293	0.0000

* Not shown in figure.

DATA TABLE 76. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (FUSED) SiO_2 (continued)

T	$\Delta L/L_0$
CURVE 59*	
293	0.0000
773	0.0245
1023	0.0365
CURVE 60*	
293	0.0000
333	0.0088
373	0.0033
473	0.0090
573	0.0132
CURVE 61*	
293	0.0000
573	0.0160
773	0.0278
1023	0.0372
CURVE 62	
1273	0.0480
773	0.0250
293	0.0000*
CURVE 63*	
293	0.0000
573	0.0140
773	0.0264
1023	0.0358
1273	0.0461
CURVE 64*	
293	0.0000
333	0.0015
373	0.0034
473	0.0092
573	0.0159
CURVE 65*	
293	0.0000
333	0.0013
373	0.0035
473	0.0095
573	0.0162

T	$\Delta L/L_0$
CURVE 66*	
293	0.0000
573	0.0151
773	0.0250
CURVE 67	
1273	0.0402
773	0.0226
293	0.0000*
CURVE 68	
293	0.0000*
573	0.0143
773	0.0235*
1023	0.0328
1273	0.0412
CURVE 69*	
293	0.0000
333	0.0016
373	0.0035
473	0.0112
CURVE 70*	
293	0.0000
333	0.0019
373	0.0037
CURVE 71*	
293	0.0000
333	0.0023
373	0.0036
473	0.0094
573	0.0132
CURVE 72*	
293	0.0000
333	0.0016
373	0.0034
473	0.0079

T	$\Delta L/L_0$
CURVE 73	
293	0.0000*
333	0.0021*
373	0.0039*
473	0.0097
573	0.0190
CURVE 74*	
293	0.0000
573	0.0151
673	0.0205
773	0.0250
873	0.0284
CURVE 75	
293	0.0000*
573	0.0162*
673	0.0205
773	0.0254*
873	0.0296
1023	0.0358
1173	0.0431
1273	0.0510
CURVE 76*	
293	0.0000
573	0.0112
CURVE 77	
293	0.0000*
573	0.0112
673	0.0175
773	0.0211
873	0.0238
1173	0.0352
1273	0.0421
CURVE 78*	
293	0.0000
573	0.0151
673	0.0198
773	0.0240

T	$\Delta L/L_0$
CURVE 79	
1173	0.0422
773	0.0245
573	0.0146
293	0.0000*
CURVE 80*	
293	0.0000
573	0.0129
673	0.0190
773	0.0235
873	0.0296
1023	0.0372
CURVE 81*	
293	0.0000
573	0.0143
673	0.0198
773	0.0254
CURVE 82*	
293	0.0000
573	0.0137
673	0.0190
1023	0.0343
1273	0.0470
CURVE 83	
293	0.0000*
573	0.0185
673	0.0251*
773	0.0307
873	0.0365
1073	0.0453
CURVE 84	
293	0.0000*
573	0.0168
673	0.0209
773	0.0259*
873	0.0313
1023	0.0380
1173	0.0440
1273	0.0490

T	$\Delta L/L_0$
CURVE 85*	
277.6	0.000028
288.1	0.000000
297.7	0.000000
308.0	0.000070
318.6	0.000136
327.9	0.000251
CURVE 86*	
318.6	0.000128
308.0	0.000063
298.0	0.000007
CURVE 87*	
267.90	-0.00116
278.15	-0.00072
286.15	-0.00034
293.15	0.00000
295.65	0.00014
300.65	0.00038
303.15	0.00051
311.15	0.00096
320.15	0.00147
328.40	0.00195
CURVE 88‡	
173	-0.004
183	-0.003*
193	-0.003
203	-0.003*
213	-0.003*
223	-0.002
233	-0.002*
243	-0.002*
253	-0.002
263	-0.001*
273	-0.001
283	-0.000
293	0.000*
303	0.000*
313	0.001
323	0.001*
333	0.002*
343	0.002*
353	0.003*
363	0.003*

T	$\Delta L/L_0$
CURVE 88 (cont.)‡	
373	0.004*
383	0.005
393	0.005
403	0.006
413	0.006
423	0.007
433	0.008
443	0.009
453	0.010
463	0.011
473	0.011*
CURVE 89*	
2.1	0.00×10^{-6}
2.5	-0.30
3.2	-0.80
3.6	-1.40
4.0	-1.80
4.2	-2.50
5.1	-4.90
5.6	-7.20
6.2	-10.60
6.9	-16.20
7.5	-22.90
CURVE 90*	
4.1	-2.1×10^{-6}
5.2	-5.3
5.3	-6.1
5.5	-6.8
5.6	-7.6
5.9	-9.4
6.2	-11.7
6.7	-14.9
7.0	-18.4
7.5	-23.2
CURVE 91*	
1.9	0.00×10^{-6}
2.3	-0.10
3.0	-0.50
3.6	-1.00
3.8	-1.30
4.0	-1.50
5.0	-3.90

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 76. THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (FUSED) SiO_2 (continued)

T	$\Delta L/L_0$
CURVE 91 (cont.)*	
5.4	-5.30×10^{-6}
6.1	-8.60
6.6	-12.50
7.0	-16.00
7.3	-19.90
7.6	-21.80
CURVE 92*	
2.9	-0.10×10^{-6}
3.2	-0.20
3.6	-0.40
3.9	-0.40
4.2	-0.60
4.9	-1.10
5.1	-1.20
5.2	-1.30
5.6	-1.80
5.7	-1.80
6.0	-2.40
6.3	-2.90
6.5	-3.30
6.9	-4.40
7.4	-6.20
8.0	-8.60
8.6	-11.90
9.2	-16.20
9.9	-22.20
CURVE 93*	
2.2	0.00×10^{-6}
2.8	-0.50
3.4	-1.00
3.8	-1.60
5.2	-5.10
5.4	-6.50
6.0	-9.60
6.6	-14.10
7.2	-19.90
CURVE 94*	
2.2	-0.10×10^{-6}
2.6	-0.30
3.3	-0.80
4.3	-2.10

T	$\Delta L/L_0$
CURVE 94 (cont.)*	
5.0	-3.60×10^{-6}
5.3	-4.80
5.7	-6.60
6.2	-9.30
6.8	-13.50
7.4	-19.20
CURVE 95*	
1.8	0.0×10^{-6}
2.6	-1.0
3.3	-1.0
4.0	-1.0
4.2	-2.0
5.0	-4.0
5.5	-6.0
5.9	-7.0
6.2	-11.0
6.5	-14.0
6.9	-18.0
7.4	-23.0
7.9	-28.0
8.3	-33.0
8.9	-42.0
9.7	-59.0
10.2	-74.0
11.1	-98.0
11.7	-114.0
12.0	-126.0
12.5	-144.0
13.1	-164.0
13.9	-198.0
14.3	-212.0
14.6	-224.0
16.2	-290.0
18.1	-388.0
CURVE 96	
288	-0.000226*
1233	0.0425
1273	0.0444
1338	0.0477

T	$\Delta L/L_0$
CURVE 97	
288	-0.000205*
573	0.0156
674	0.0213
774	0.0270
873	0.0314*
973	0.0339
1073	0.0365
1173	0.0399
1273	0.0442
1329	0.0470
CURVE 98	
288	-0.000205*
573	0.0164*
673	0.0225
773	0.0280
873	0.0318
973	0.0351
1073	0.0378
1173	0.0413
1273	0.0453
1333	0.0486
CURVE 99*	
288	-0.000205
573	0.0163
672	0.0222
773	0.0278
874	0.0314
974	0.0338
1073	0.0370
1173	0.0404
1273	0.0448
1333	0.0482
CURVE 100*	
288	-0.000226
1233	0.0425
1273	0.0441
1338	0.0471

T	$\Delta L/L_0$
CURVE 101	
288	-0.000205*
573	0.0161*
673	0.0220
773	0.0275
873	0.0316*
974	0.0349*
1074	0.0375
1173	0.0407
1273	0.0450*
1334	0.0480
CURVE 102*	
288	-0.000205
573	0.0156
674	0.0212
773	0.0266
874	0.0304
974	0.0334
1074	0.0365
1173	0.0395
1273	0.0446
1330	0.0482
CURVE 103	
288	-0.000205*
573	0.0162*
673	0.0226
773	0.0284
873	0.0323
973	0.0359
1073	0.0392
1173	0.0434
1223	0.0458

* Not shown in figure.

DATA TABLE 76. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SILICON DIOXIDE (FUSED) SiO_2

[Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\,K^{-1}$]

T	α
CURVE 36	
10	-0.409
20	-0.747
30	-0.854
40	-0.867
50	-0.846
60	-0.829
70	-0.801
80	-0.767
90	-0.727
100	-0.679
110	-0.621
120	-0.556
130	-0.485
140	-0.412
CURVE 88‡	
173	0.19
183	0.21
193	0.23
203	0.25
213	0.27
223	0.28
233	0.30
243	0.33
253	0.34
263	0.36
273	0.38
283	0.40
293	0.42
303	0.44*
313	0.46*
323	0.48*
333	0.49*
343	0.49*
353	0.54*
363	0.56*
373	0.57*
383	0.59*
393	0.62*
403	0.68*
413	0.74*
423	0.75*

T	α
CURVE 88 (cont.)‡	
433	0.78*
443	0.82*
453	0.86*
463	0.92*
473	0.99*
CURVE 89	
3.39	-0.011
3.78	-0.015*
4.11	-0.021
4.68	-0.030
5.25	-0.041*
6.50	-0.082
7.15	-0.104
7.80	-0.132
8.31	-0.162
9.24	-0.194
10.00	-0.238
11.15	-0.291
12.1	-0.321
14.5	-0.405
15.9	-0.460
20.4	-0.583
22.8	-0.635
23.6	-0.644
27.0	-0.679
CURVE 91	
3.34	-0.009*
3.78	-0.014*
4.57	-0.022*
5.23	-0.036*
5.75	0.046*
6.83	-0.083*
7.48	-0.099*
7.76	-0.113*
8.86	-0.154*
11.05	-0.271
13.50	-0.380
16.30	-0.496
17.90	-0.545

T	α
CURVE 91 (cont.)	
19.4	-0.599
23.1	-0.676
24.8	-0.717
27.0	-0.738
CURVE 92*	
3.53	-0.003
3.98	-0.004
4.52	-0.006
5.05	-0.009
5.40	-0.011
5.84	-0.015
5.94	-0.015
6.22	-0.018
6.57	-0.023
7.16	-0.029
7.71	-0.039
8.30	-0.052
8.95	-0.069
9.51	-0.082
10.2	-0.102
11.0	-0.127
11.5	-0.139
12.5	-0.175
13.5	-0.208
14.9	-0.264
16.1	-0.304
17.6	-0.359
18.9	-0.415
20.8	-0.470
23.0	-0.542
24.4	-0.583
26.1	-0.646
27.8	-0.667
29.3	-0.655
CURVE 93*	
3.32	-0.011
3.62	-0.014
3.98	-0.019
4.60	-0.029

T	α
CURVE 93 (cont.)*	
5.27	-0.043
5.70	-0.054
6.30	-0.071
6.83	-0.095
7.61	-0.122
8.35	-0.150
9.06	-0.191
9.68	-0.219
10.60	-0.268
11.95	-0.305
12.50	-0.350
13.20	-0.354
14.95	-0.446
16.70	-0.503
18.50	-0.551
24.40	-0.661
CURVE 94*	
3.02	-0.007
4.00	-0.016
5.06	-0.029
6.04	-0.052
6.50	-0.066
7.13	-0.093
7.93	-0.124
8.62	-0.146
9.38	-0.183
10.1	-0.221
10.9	-0.256
11.7	-0.285
12.5	-0.319
14.0	-0.375
20.5	-0.592
22.2	-0.651
26.1	-0.713
27.9	-0.760
29.8	-0.760
CURVE 95*	
4	-0.020
6	-0.068

T	α
CURVE 95 (cont.)*	
8	-0.143
10	-0.235
12	-0.330
15	-0.450
20	-0.590
25	-0.660

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

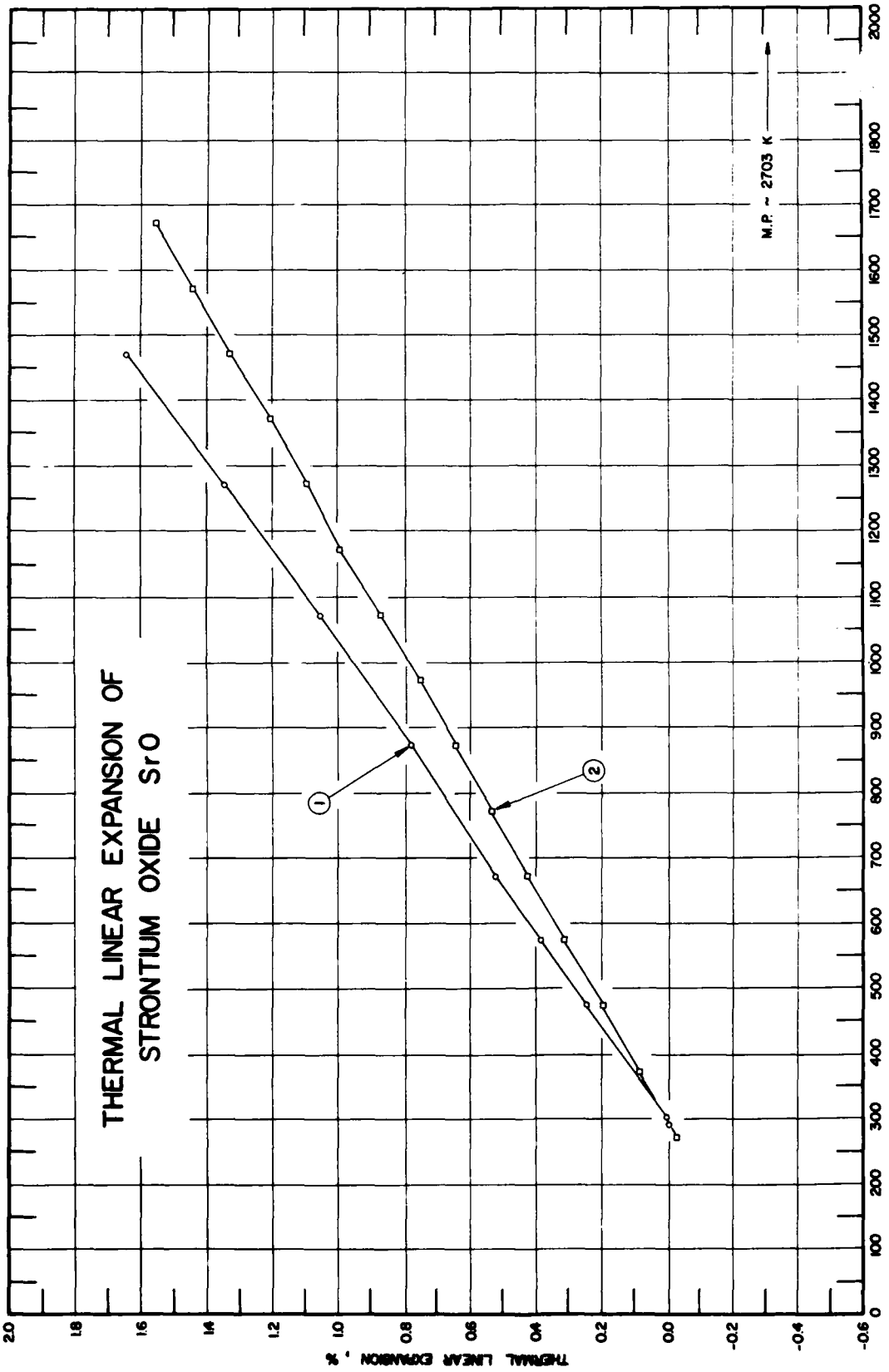

THERMAL LINEAR EXPANSION OF
STRONTIUM OXIDE SrO
M.P. ~ 2703 K
1
2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
2000

FIGURE 77

SPECIFICATION TABLE 77. THERMAL LINEAR EXPANSION OF STRONTIUM OXIDE SrO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	74	Beals, R.J. and Cook, R. L.	1957	X	301-1473		Cubic structure, reagent grade specimen; data from smooth curve; zero-point correction of 0.006% determined by graphical extrapolation.
2	194	Rinshaw, S.J. and Ketchen, E. E.	1969	L	273-1673		Specimen 0.5 in. long; prepared by hot pressing; data originally reported by E. Lamb, ORNL Isotopic Power Fuels Quarterly Report for Period Ending September 30, 1966, USAEC Rept. ORNL-4045 (Classified), Oak Ridge National Laboratory.

DATA TABLE 77. THERMAL LINEAR EXPANSION OF STRONTIUM OXIDE SrO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
301	0.006
473	0.253
573	0.384
673	0.520
873	0.784
1073	1.058
1273	1.349
1473	1.643
CURVE 2	
273	-0.022
373	0.088
473	0.198
573	0.311
673	0.422
773	0.533
873	0.644
973	0.755
1073	0.874
1173	0.986
1273	1.098
1373	1.210
1473	1.333
1573	1.446
1673	1.559

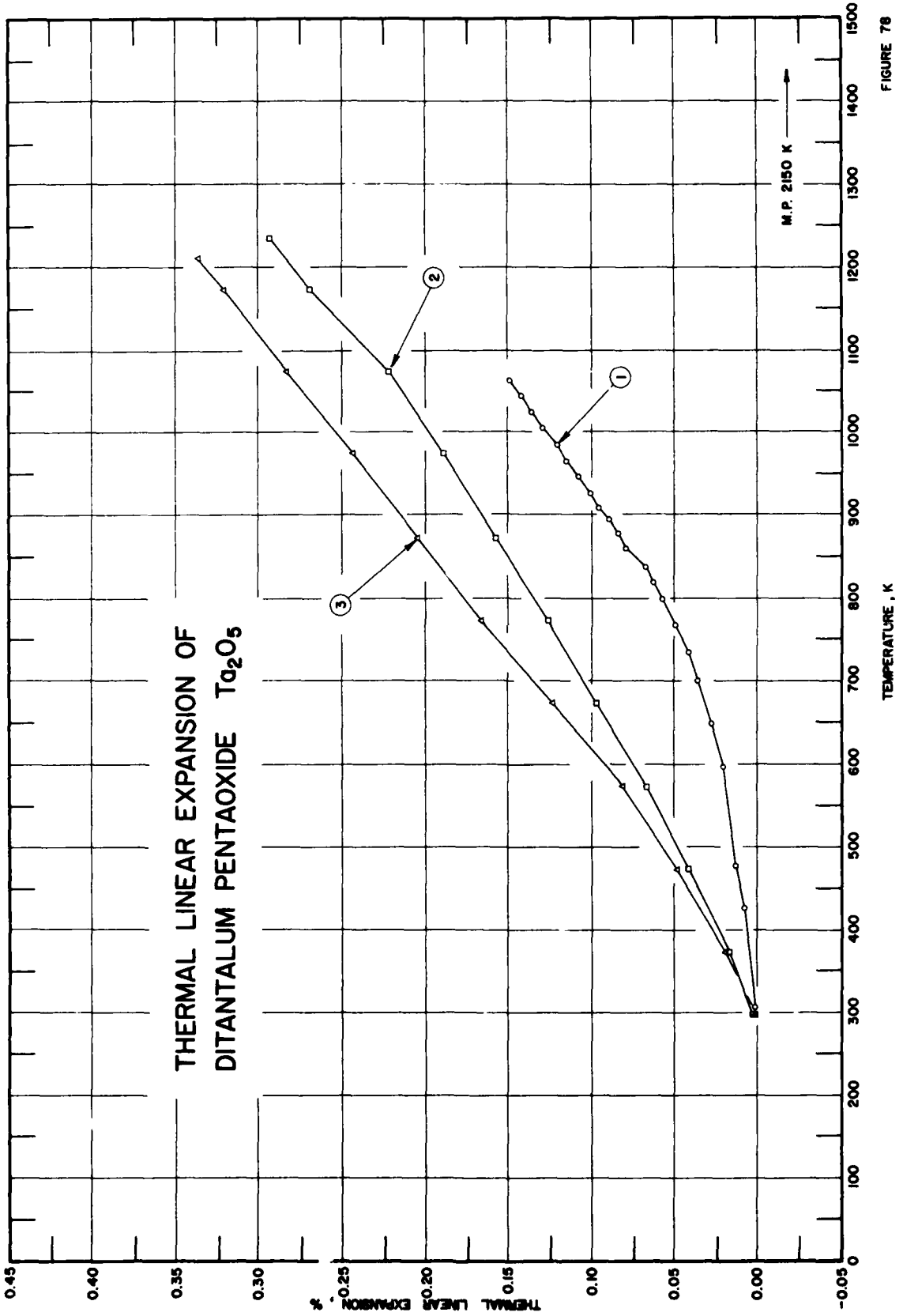

THERMAL LINEAR EXPANSION OF
DITANTALUM PENTAOXIDE Ta_2O_5
M.P. 2150 K
1
2
3
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 78

SPECIFICATION TABLE 78. THERMAL LINEAR EXPANSION OF DITANTALUM PENTAOXIDE Ta_2O_5

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	19	Durbin, E.A. and Harman, C.G.	1952	I	307-1061		Cylindrical specimen, 0.125 in. diameter, 0.25 in. long; powder pressed in steel die at pressure 10 000 psi, 1689 K and cooled in furnace.
2	333	Brown, J.J., Jr.	1964	L	298-1235	α-Ta_2O_5	Bar specimen, approximately 10 x 1 x 1 cm; heated at 125 C per hr in Nichrome-wound vertical tube furnace; data from smoothed curve; zero-point correction of 0.003% determined by graphical extrapolation.
3	333	Brown, J.J., Jr.	1964	L	298-1210	β-Ta_2O_5	Similar to the above specimen; data from smoothed curve; zero-point correction of 0.001% determined by graphical extrapolation.

DATA TABLE 78. THERMAL LINEAR EXPANSION OF DITANTALUM PENTAOXIDE Ta_2O_5

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
307	0.002
424	0.008
475	0.014
595	0.022
649	0.029
699	0.036
733	0.042
767	0.050
796	0.058
819	0.064
838	0.068
860	0.080
876	0.084
893	0.090
907	0.096
923	0.102
943	0.108
962	0.116
983	0.121
1002	0.128
1025	0.136
1043	0.143
1061	0.148

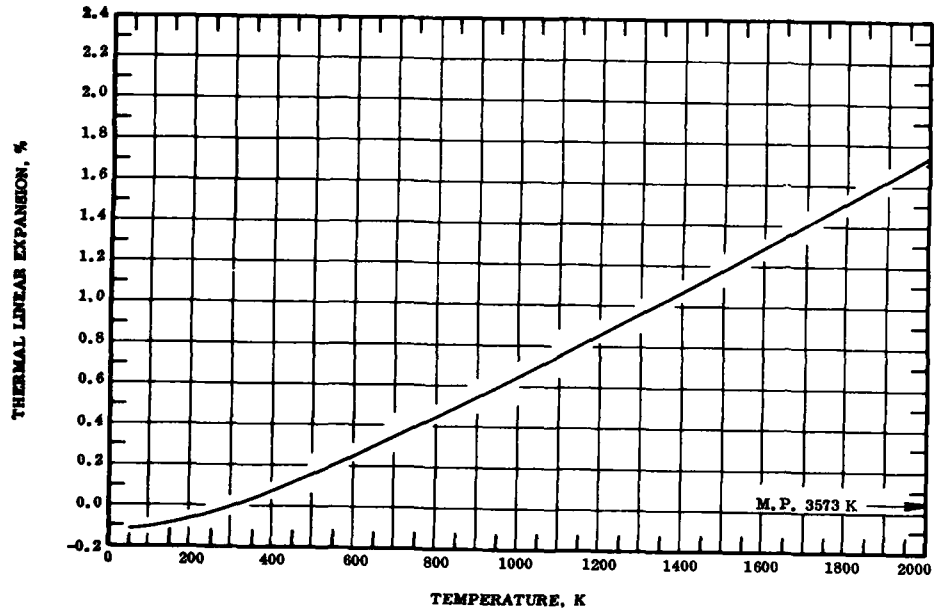
CURVE 2

T	$\Delta L/L_0$
298	0.003
373	0.017
473	0.042
573	0.067
673	0.097
773	0.126
873	0.157
973	0.188
1073	0.223
1173	0.269
1235	0.293

CURVE 3

T	$\Delta L/L_0$
298	0.001
373	0.020
473	0.049
573	0.083
673	0.124
773	0.166
873	0.205
973	0.244
1073	0.283
1173	0.323
1210	0.337

FIGURE AND TABLE NO. 79R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF THORIUM DIOXIDE ThO_2



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
50	-0.115	5.4
100	-0.105	6.0
150	-0.095	6.5
200	-0.063	7.0
250	-0.030	7.4
293	0.000	7.7
400	0.080	8.3
500	0.165	8.8
600	0.250	9.2
700	0.350	9.4
800	0.440	9.6
900	0.540	9.8
1000	0.640	10.1
1100	0.740	10.3
1200	0.840	10.4
1300	0.950	10.6
1400	1.060	10.7
1500	1.170	10.9
1600	1.280	11.2
1700	1.400	11.4
1800	1.505	11.6
1900	1.620	11.8
2000	1.730	12.1

REMARKS

The recommended values are based on the data for pure samples and are considered accurate to within ±3%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.179 + 5.097 \times 10^{-4} T + 3.732 \times 10^{-7} T^2 - 7.594 \times 10^{-11} T^3 \quad (150\text{-}2000\ K)$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±5%.

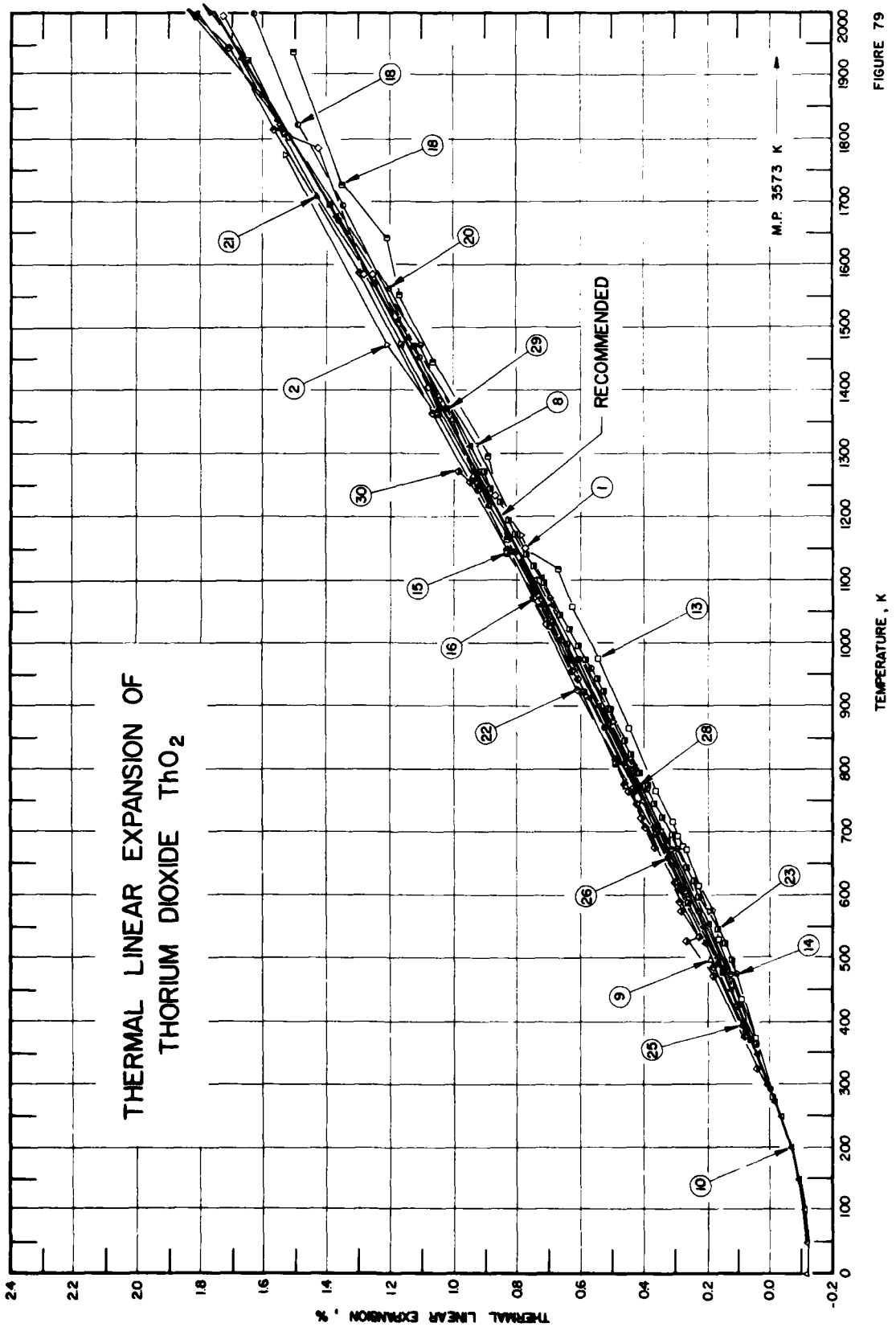

THERMAL LINEAR EXPANSION OF
THORIUM DIOXIDE ThO_2
RECOMMENDED
M.P. 3573 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
18
18
21
20
2
29
8
30
1
15
16
13
22
28
26
23
14
9
25
10

FIGURE 79

SPECIFICATION TABLE 79. THERMAL LINEAR EXPANSION OF THORIUM DIOXIDE ThO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	172	Aronson, S., Cisney, E., and Gingerich, K.A.	1967	X	1156-2348		99.99 pure; obtained from Electronic Space Products, Inc., Los Angeles, Calif.; (511), (531), and (600) lines used for thermal expansion; m.p. 3473K; CuKα radiation used; reference temperature reported at room temperature (295 to 298 K); no zero-point correction given.
2	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	298-1773		Specimen 0.5 x 0.5 in. cross section, 7 in. long; fine fused grain; ends sawed at rake and to point.
3*	8	Kummer, D.L., Rosenthal, J.J., and Lum, D.W.	1965	L	256-2473	ZIRCOA Y-1193 C	Specimen obtained from Zircoa Co.; density 7.05 g cm^{-3}; shrinkage began at 2470 K about 2-2.5%; data from smoothed curve; zero-point correction of -0.026% determined by graphical interpolation.
4*	8	Kummer, D.L., et al.	1965	L	256-1936	Norton LT-5006	Specimen obtained from Norton Co.; density 2.00 g cm^{-3}; shrinkage began at 1920 K about 9.8-10.0%; data from smoothed curve; zero-point correction of -0.026% determined by graphical interpolation.
5*	8	Kummer, D.L., et al.	1965	L	256-1019	MAC LT-1	Specimen density 3.20 g cm^{-3}; shrinkage began at 950 K about 10.2-11.0%; data from smoothed curve; zero-point correction of -0.025% determined by graphical interpolation.
6*	8	Kummer, D.L., et al.	1965	L	256-1335	MAC DT-1	Similar to the above specimen; shrinkage began at 1280 K about 10.0-12.2%; data from smoothed curve; zero-point correction of -0.026% determined by graphical interpolation.
7*	109	Ohnysty, B., Stausfield, O.M., Stetson, A.R., and Metcalfe, A.G.	1965	T	1156-2418		99.93 pure; bar specimen 0.3 x 0.4 x 2.5 in.; obtained from Vitro Chemical Co.; powder pressed with 4.0 polyethylene glycol binder, pressed into bar; binder burned out by heating at 1255 K for 1 hr; heated in argon atm at 1644 K, sintered at 2477 K for 1 hr; reference temperature at room temperature assumed at 293 K.
8	10	Mauer, F.A. and Bolz, L.H.	1955	X	273-1677		99.98+ pure; fused specimen obtained from Norton Co.; lattice parameter at 273 K 5.5960 Å; zero-point correction of -0.015% determined by graphical interpolation.
9	61	Grain, C.F. and Campbell, W.J.	1962	X	300-1354		99.9 pure; ground, spread on alumina holder, heated with gas-oxygen torch for 15 min, cooled; mixed with platinum powder as internal standard; zero-point correction of 0.01% determined by graphical extrapolation.
10	20	Wachtman, J.B., Jr., Scuderi, T.G., and Cleek, G.W.	1962	I	0-1100		0.01-0.1 Al, Mg and Si impurities; polycrystalline specimen; obtained from Norton Co.; cold-pressed and sintered; density 9.66 g cm^{-3}; values of thermal expansion computed from equation with values of parameters; zero-point correction of -0.0170% determined by graphical interpolation.
11*	63	Pears, C.D.	1963	L	285-2473	Run E-19	Specimen initial length 2.880 in.; obtained from Zirconium Corp. of America; pressed and sintered; density 9.10 g cm^{-3} at 298 K before exposure by ASTM method B311-58, 8.90 g cm^{-3} by wax-coating specimen, and 9.69 g cm^{-3} by immersion in xylene; expansion measured in helium atm; report error 5%.
12*	63	Pears, C.D.	1963	L	2473-283	Run E-19	The above specimen; 2.850 in. long; expansion measured with decreasing temperature; zero-point correction of 1.064% determined by graphical interpolation.
13	163	Skinner, B.J.	1957	X	281-1060		0.1-0.5 Si, Mg and < 0.05 other impurities; unit cell edge reported at 281.7 K is 5.59475 Å; 5.59510 Å at 293 K determined by graphical interpolation.

*Not shown in figure.

SPECIFICATION TABLE 79. THERMAL LINEAR EXPANSION OF THORIUM DIOXIDE ThO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
14	173	Springer, J.R., Eldridge, E.A., Goodyear, M.V., Wright, T.R., and Lagedrost, J.E.	1967	L	293-2273	C-1 specimen	0.004 Si, 0.0025 Mg, <0.0025 Cr, 0.002 Fe, 0.0015 Al, 0.001 Ni, 0.003 Mo; rod specimen 0.375 in. dia, 1.5-1.75 in. long; clean, comminuted powder; dried, wet mixed with binder and solvent, dried, pressed at 60 000 psi, calcined at 900 C in CO_2 atm; heating rate 7 C per min; reported error < 2.0%.
15	114	Ohnysty, B. and Rose, F.K.	1964	T	296-2759		Bar specimen 0.25 x 0.25 x 1.25 in.; fabricated by Norton Co.
16	139	Ferguson, I.F., Street, R.S., and D'Eye, R.W.M.	1960	X	288-1246		Crystalline specimen prepared by decomposing thorium oxalate in air atm at 1073 K, heated in vacuum at 2273 K; expansion measured using CuK_{α} radiation; lattice parameter reported at 288 K is 5.5964 Å; 5.5966 Å at 293 K determined by graphical interpolation.
17*	43	Eisenstein, A.	1946	X	293, 1148		Cubic crystal specimen as coating; reported error ±3%.
18	25	Baldock, P.J., Spindler, W.E., and Baker, T.W.	1968	X	299-2001	Specimen 1	99.9 pure specimen; powder cold-pressed into brick and sintered at 2073 K for 4 hrs; lattice parameter reported at 299 K is 5.5998 Å; 5.5997 Å at 293 K determined by graphical extrapolation.
19*	25	Baldock, P.J., et al.	1968	X	503-2194	Specimen 2	Similar to the above specimen; only data on the lattice parameter are tabulated.
20	25	Baldock, P.J., et al.	1968	X	299-2334	Specimen 3	Similar to the above specimen; lattice parameter reported at 299 K is 5.5971 Å; 5.5968 Å at 293 K determined by graphical extrapolation.
21	175	Valentich, J.	1969	L	303-2485		Specimen 0.6 cm diameter, 0.6 to 10 cm long; expansion measured in vacuum; zero-point correction of 0.009% determined by graphical extrapolation.
22	175	Valentich, J.	1969	L	2376-484		The above specimen; expansion measured with decreasing temperature; zero-point correction of 0.162% determined by graphical extrapolation.
23	45	Brett, N.H. and Russell, L.E.	1960	L	298-1273		Specimen 7.4 mm long; powder compressed with 2 wt% naphthalene binder at 3000 kg cm^{-2} and fired in argon atmosphere at 1873 K for 2 hrs; density 6.44 g cm^{-3}; zero-point correction of 0.0002% determined by graphical extrapolation.
24*	28	Merritt, G.E.	1926	I	296-442		Semitransparent, frangible specimen; fused at Bureau of Standards without formation of carbide; zero-point correction of 0.002% determined by graphical extrapolation.
25	28	Merritt, G.E.	1926	I	391-1061		The above specimen; expansion measured on second test; zero-point correction of 0.008% determined by graphical extrapolation.
26	28	Merritt, G.E.	1926	I	490-1130		The above specimen; expansion measured on third test; zero-point correction of 0.015% determined by graphical extrapolation.
27	176	Hoch, M. and Momin, A.C.	1969	X	298-2363		99.9 pure; rod specimen 0.15 in diameter, 0.16 in. long; obtained from Fairmont Chemical Co., Inc., Newark, N.J.; pressed without any binder, compacted into cylindrical rod; reported error ±0.1-0.3%; lattice parameter reported at 298 K is 5.595 Å; 5.595 Å at 293 K assumed by TPRC.
28	174	Lang, S.M. and Knudson, F.P.	1956	I	303-1073		0.5 CaO; rod specimen; pressed at 3000, then 30 000 psi and heated for 1 hr in oxydizing atm at 2073 K; density 9.71 g cm^{-3}; zero-point correction of 0.004% determined by graphical extrapolation.

*Not shown in figure.

SPECIFICATION TABLE 79. THERMAL LINEAR EXPANSION OF THORIUM DIOXIDE ThO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
29	174	Lang, S.M. and Knudson, F.P.	1956	L	301-1673		Similar to the above specimen except using different method for measurement; zero-point correction of 0.006% determined by graphical extrapolation.
30	142	Roth, J. and Halteman, E.K.	1965	X	296-1273		Specimen prepared by crushing and sieving -200 mesh powder; lattice parameter reported at 296 K is 5.5965 Å; 5.5963 Å at 293 K determined by graphical extrapolation.
31*	596	Stacy, D.W.	1971	X	293-2178		Specimen 99.94 ThO_2, 0.003 Al, 0.01 Ca, 0.008 Co, 0.008 Ni, 0.01 Si, and 0.02 Zr; obtained from Zircoa Corp. (Solon, Ohio); received as a sintered disk and ground to -325 mesh for X-ray analysis; average standard deviation of lattice parameters 0.0004 A; lattice parameter reported at 293 K is 5.593 Å.
32*	329	Schraeder, T.F., Carniglia, S.C., and Brown, S.D.	1968	X	313-1567		Powdered specimen derived by crushing portions of rod sample; expansion measured of unit cell of four molecules; volume of unit cell reported at 313 K is 175.29 $Å^3$; 175.21 $Å^3$ at 293 K determined by graphical extrapolation.
33*	329	Schraeder, T.F., et al.	1968	X	310-1769	$ThO_{1.998}$	Similar to the above specimen; volume of unit cell reported at 310 K is 174.91 $Å^3$; 174.88 $Å^3$ at 293 K determined by graphical extrapolation.
34*	329	Schraeder, T.F., et al.	1968	X	310-1633	$ThO_{1.997}$	Similar to the above specimen; volume of unit cell reported at 310 K is 174.53 $Å^3$; 174.50 $Å^3$ at 293 K determined by graphical extrapolation.

* Not shown in figure.

DATA TABLE 79. THERMAL LINEAR EXPANSION OF THORIUM DIOXIDE ThO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
1156	0.778
1235	0.877
1383	1.053
1404	1.092
1586	1.253
1586	1.284
1783	1.428
1807	1.521
1992	1.734
2211	1.952*
2348	2.129*
CURVE 2	
298	0.004*
573	0.199
873	0.493
1173	0.792
1473	1.215
1773	1.539
CURVE 3*	
256	-0.026
683	0.270
1087	0.601
1471	0.967
2156	1.700
2319	1.880
2388	1.910
2473	1.920
CURVE 4*	
256	-0.026
683	0.270
1087	0.601
1198	0.961
1586	1.050
1659	1.100
1847	1.160
1936	1.140
CURVE 5*	
256	-0.025
683	0.259

T	$\Delta L/L_0$
CURVE 5 (cont.)*	
845	0.325
936	0.359
1019	0.355
CURVE 6*	
256	-0.026
683	0.270
1087	0.594
1147	0.611
1235	0.604
1335	0.549
CURVE 7*	
1156	0.830
1436	1.119
1688	1.376
1897	1.677
2418	2.331
CURVE 8	
273	-0.015
299	0.004
481	0.149
689	0.332
897	0.521
1105	0.721
1313	0.934
1521	1.179
1677	1.370
CURVE 9	
300	0.01
496	0.19
771	0.46
1028	0.70
1267	0.94
1354	1.01
CURVE 10	
0	-0.117
50	-0.116
100	-0.109

T	$\Delta L/L_0$
CURVE 10 (cont.)	
150	-0.0911
200	-0.0643
250	-0.0316
300	0.00490*
350	0.0442
400	0.08530
450	0.1279
500	0.1717
550	0.2164
600	0.2619
650	0.3081
700	0.3549
750	0.4022
800	0.4502
900	0.5474
1000	0.6465
1100	0.7474
CURVE 11*	
285	0.000
403	0.046
517	0.140
723	0.343
872	0.502
1110	0.729
1284	0.874
1460	1.028
1641	1.184
1682	1.250
1839	1.433
1978	1.544
2232	1.672
2345	1.638
2452	1.287
2473	1.103
CURVE 12*	
2473	2.167
2109	1.712
1854	1.460
1733	1.317
1418	0.970
1288	0.871
1035	0.616
283	-0.003

T	$\Delta L/L_0$
CURVE 13	
281.7	-0.0063
298.2	0.0027*
306.2	0.0084*
307.3	0.0091*
376.3	0.0539
435.2	0.0947
529.4	0.1634
616.3	0.2309
671.4	0.2786
676.2	0.2786*
677.4	0.2824
694.5	0.3000
719.2	0.3178
769.1	0.3632
867.1	0.4529
973.2	0.5503
1060.4	0.6327
CURVE 14	
293	0.00
473	0.13
673	0.30
873	0.49*
1073	0.70
1273	0.92
1473	1.14
1673	1.37
1873	1.60
2073	1.84*
2273	2.08*
CURVE 15	
296	0.000*
366	0.056
477	0.159
588	0.263
699	0.362
810	0.488
922	0.595
1033	0.698
1144	0.817
1255	0.927
1366	1.050
1477	1.164
1588	1.280*

T	$\Delta L/L_0$
CURVE 15 (cont.)	
1699	1.393
1810	1.519
1922	1.653
2033	1.779*
2144	1.924*
2255	2.046*
2366	2.192*
2477	2.331*
2588	2.474*
2699	2.623*
2759	2.681*
CURVE 16	
288	-0.00357*
378	0.0822
620	0.311
745	0.425
776	0.463
941	0.606
956	0.629
1071	0.750
1246	0.924
CURVE 17*	
293	0.000
1148	0.966
CURVE 18	
299	0.00178
577	0.186
770	0.395
960	0.566
1219	0.887
1455	1.119
1697	1.357
1843	1.493
2001	1.636
CURVE 19*	
503	5.6079
666	5.6168
892	5.6290
1097	5.6402
1337	5.6542

T	$\Delta L/L_0$
CURVE 19 (cont.)*	
1585	5.6692
2194	5.7045
CURVE 20	
299	0.00536
552	0.200
801	0.431
1063	0.695
1311	0.945
1565	1.202
1830	1.559
2070	1.808*
2334	2.003*
CURVE 21	
303	0.009*
1148	0.806
1261	0.927
1372	1.049
1485	1.144
1589	1.256*
1706	1.416
1817	1.544
1929	1.669
2033	1.798*
2148	1.937*
2261	2.077*
2378	2.233*
2485	2.386*
CURVE 22	
2376	2.353*
2263	2.161*
2154	2.010*
2037	1.848*
1932	1.708
1814	1.564
1704	1.433*
1589	1.291
1478	1.176*
1367	1.070
1258	0.948*
1150	0.831
1030	0.714*

*Not shown in figure.

DATA TABLE 79. THERMAL LINEAR EXPANSION OF THORIUM DIOXIDE ThO_2 (continued)

T	$\Delta L/L_0$
CURVE 22 (cont.)	
924	0.608
814	0.498
706	0.400
589	0.296
484	0.182
CURVE 23	
298	0.0002*
348	0.0018*
373	0.0119*
398	0.0302*
423	0.0502*
448	0.0727*
473	0.0977*
498	0.1252
523	0.1452
548	0.1752
573	0.1952*
598	0.2252
623	0.2427
648	0.2702
673	0.2952*
698	0.3177
723	0.2427
748	0.3677
773	0.3902
798	0.4202
823	0.4427
848	0.4627
873	0.4902*
898	0.5127
923	0.5327
948	0.5552
973	0.5877
998	0.6127
1023	0.6402
1048	0.6652
1073	0.6927*
1098	0.7202
1123	0.7452
1148	0.7752
1173	0.8027
1198	0.8277
1223	0.8577
1248	0.8852
1273	0.9102

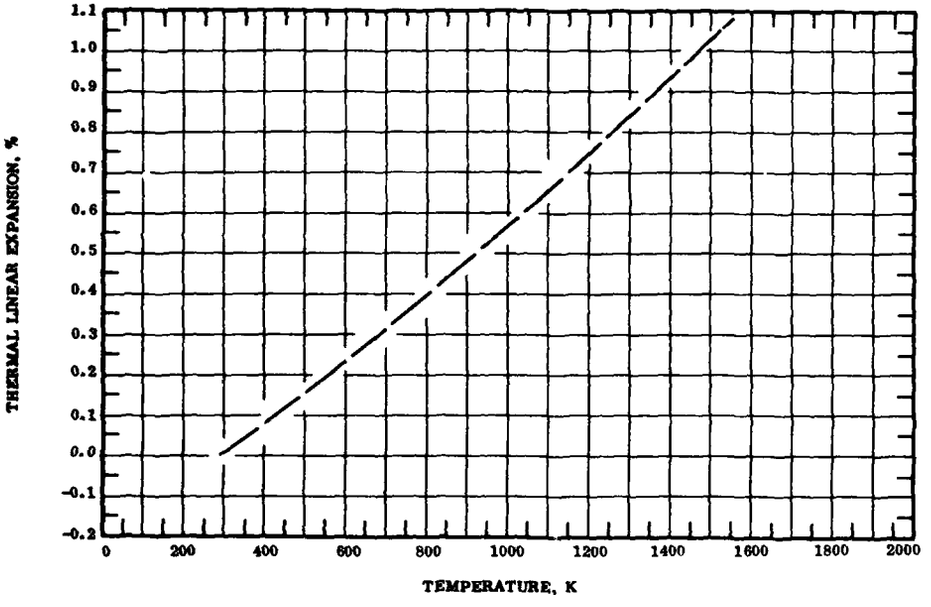
T	$\Delta L/L_0$
CURVE 24*	
296	0.002
378	0.067
442	0.122
CURVE 25	
391	0.088
523	0.206
609	0.287
708	0.376
810	0.470
911	0.577
1009	0.677
1061	0.728
CURVE 26	
490	0.176
661	0.329
869	0.530
974	0.630
1130	0.785
CURVE 27	
298	0.000*
1118	0.679
1168	0.822
1298	0.894
1448	1.072
1553	1.179
1643	1.215
1728	1.358
1938	1.501
2023	1.644*
2078	1.734*
2168	1.787*
2238	1.930*
2298	2.019*
2363	2.091*
CURVE 28	
303	0.004*
373	0.044*
473	0.133
573	0.225
673	0.320

T	$\Delta L/L_0$
CURVE 28 (cont.)	
673	0.320
773	0.418
873	0.519
973	0.623*
1073	0.730
CURVE 29	
301	0.006*
373	0.065
473	0.147*
573	0.232*
673	0.320*
773	0.411*
873	0.505
973	0.602
1073	0.702*
1173	0.805*
1273	0.911*
1373	1.020
1473	1.132
1573	1.246
1673	1.365*
CURVE 30	
296	0.0035*
298	0.0035*
323	0.0464
373	0.0679*
423	0.1054
470	0.1822
529	0.2662
532	0.2358
571	0.2876
616	0.3001
677	0.3716
723	0.4109
766	0.4467
770	0.4395
771	0.4467*
1030	0.7129
1259	0.9488
1273	0.9810

T	$\Delta L/L_0$
CURVE 31*	
293	0.000
1264	0.897
1503	1.0978
1551	1.1657
1611	1.244
1646	1.2372
1677	1.3713
1817	1.5143
1894	1.648
1992	1.732
2009	1.7950
2071	1.8576
2094	1.9256
2152	2.0078
2170	2.000
2178	2.040
CURVE 32*	
313	0.015
925	0.502
1320	0.942
1567	1.348
CURVE 33*	
310	0.006
680	0.279
1008	0.531
1206	0.704
1769	1.650
CURVE 34*	
310	0.006
683	0.288
1262	0.753
1633	1.301

*Not shown in figure.

FIGURE AND TABLE NO. 80R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF THULIUM OXIDE Tm_2O_3



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	7.0
400	0.077	7.3
500	0.150	7.6
600	0.229	7.9
700	0.309	8.1
800	0.392	8.4
900	0.477	8.6
1000	0.564	8.8
1100	0.653	9.0
1200	0.744	9.2
1300	0.836	9.3
1400	0.930	9.5
1500	1.025	9.6
1550	1.074	9.7

REMARKS

The provisional values are considered accurate to within ±7% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.191 + 6.015 \times 10^{-4}\, T + 1.802 \times 10^{-7}\, T^2 - 2.704 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

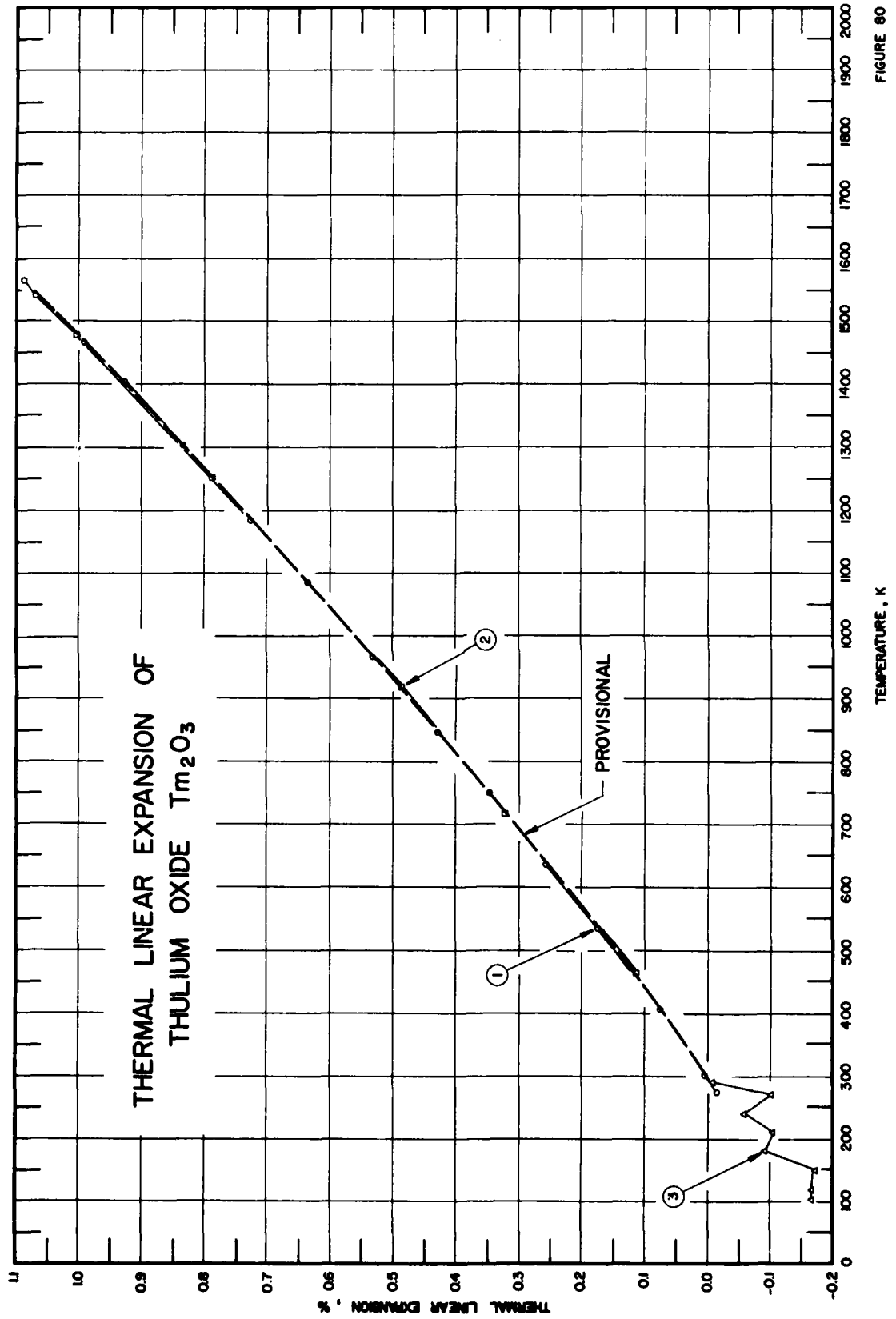

THERMAL LINEAR EXPANSION OF
THULIUM OXIDE Tm_2O_3
PROVISIONAL
1
2
3
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 80

SPECIFICATION TABLE 80. THERMAL LINEAR EXPANSION OF THULIUM OXIDE Tm_2O_3

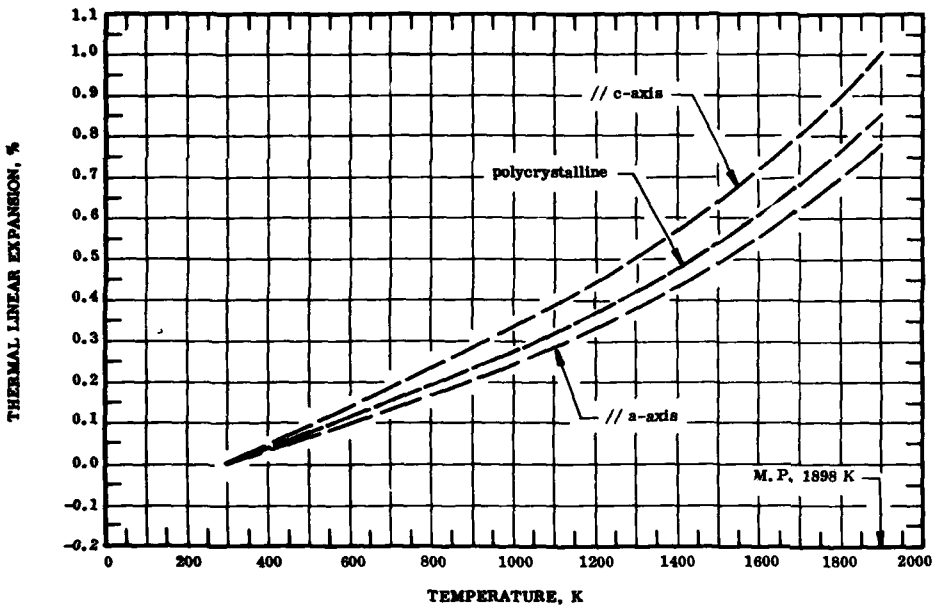
Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	68	Stecura, S. and Campbell, W.J.	1961	X	273-1568		99.9 pure; specimen obtained from Lindsey Chemical Co.; sintered at 1473 K for 24 hr, packed into alumina holder, sintered at 1573 K for 12 hr, cooled to 673 K, stored in desiccator; reported error ±2%; unit cell parameter reported at 273.2 K is 10.4843 Å; zero-point correction of -0.014% determined by graphical interpolation.
2	68	Stecura, S. and Campbell, W.J.	1961	X	1479-463		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.014% determined by graphical extrapolation.
3	177	Davenport, J.C.	1965	X	291-104		99.9 pure; specimen obtained from Research Chemicals, Inc.; prepared in form of thin disk of 1 cm diameter with lucite cement as binder; annealed at 1373 K for 48 hr; unit cell parameter reported at 291 K is 10.4883 Å; 10.4892 Å at 293 K determined by graphical extrapolation; expansion measured with decreasing temperature.

DATA TABLE 80. THERMAL LINEAR EXPANSION OF THULIUM OXIDE Tm_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
273	-0.014
301	0.005
407	0.076
537	0.175
637	0.258
750	0.346
848	0.430
968	0.532
1087	0.638
1184	0.729
1304	0.835
1405	0.929
1469	0.991
1544	1.070
1568	1.090
CURVE 2	
1479	1.002
1251	0.789
919	0.487
CURVE 2 (cont.)	
718	0.322
463	0.115
CURVE 3	
291	-0.0085
270	-0.1020
240	-0.0581
210	-0.1048
180	-0.0915
150	-0.1716
120	-0.1668
104	-0.1668

FIGURE AND TABLE NO. 81R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF TIN DIOXIDE SnO_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	3.8
400	0.052	0.035	0.038	3.8
500	0.098	0.067	0.076	3.8
600	0.144	0.098	0.115	3.8
700	0.189	0.135	0.152	3.8
800	0.235	0.168	0.190	3.9
900	0.283	0.205	0.231	4.2
1000	0.332	0.244	0.274	4.4
1100	0.385	0.285	0.319	4.7
1200	0.442	0.331	0.368	5.2
1300	0.503	0.380	0.422	5.6
1400	0.570	0.433	0.480	5.9
1500	0.641	0.491	0.541	6.4
1600	0.720	0.554	0.608	7.1
1700	0.808	0.623	0.684	7.9
1800	0.900	0.698	0.766	8.6
1900	1.010	0.780	0.857	9.0

REMARKS

The provisional values for the axial thermal expansion for sample of tetragonal structure are based on the more recent experimental data (curves 7 and 8). The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ± 7% and are represented approximately by the following equations:

$$\underline{//\ c\text{-axis}}: \quad \Delta L/L_0 = -0.159 + 6.023 \times 10^{-4}\ T - 2.411 \times 10^{-7}\ T^2 + 1.303 \times 10^{-10}\ T^3$$

$$\underline{//\ a\text{-axis}}: \quad \Delta L/L_0 = -0.102 + 3.718 \times 10^{-4}\ T - 1.080 \times 10^{-7}\ T^2 + 8.234 \times 10^{-11}\ T^3$$

$$\underline{\text{polycrystalline}}: \quad \Delta L/L_0 = -0.120 + 4.475 \times 10^{-4}\ T - 1.512 \times 10^{-7}\ T^2 + 9.796 \times 10^{-11}\ T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ± 10%.

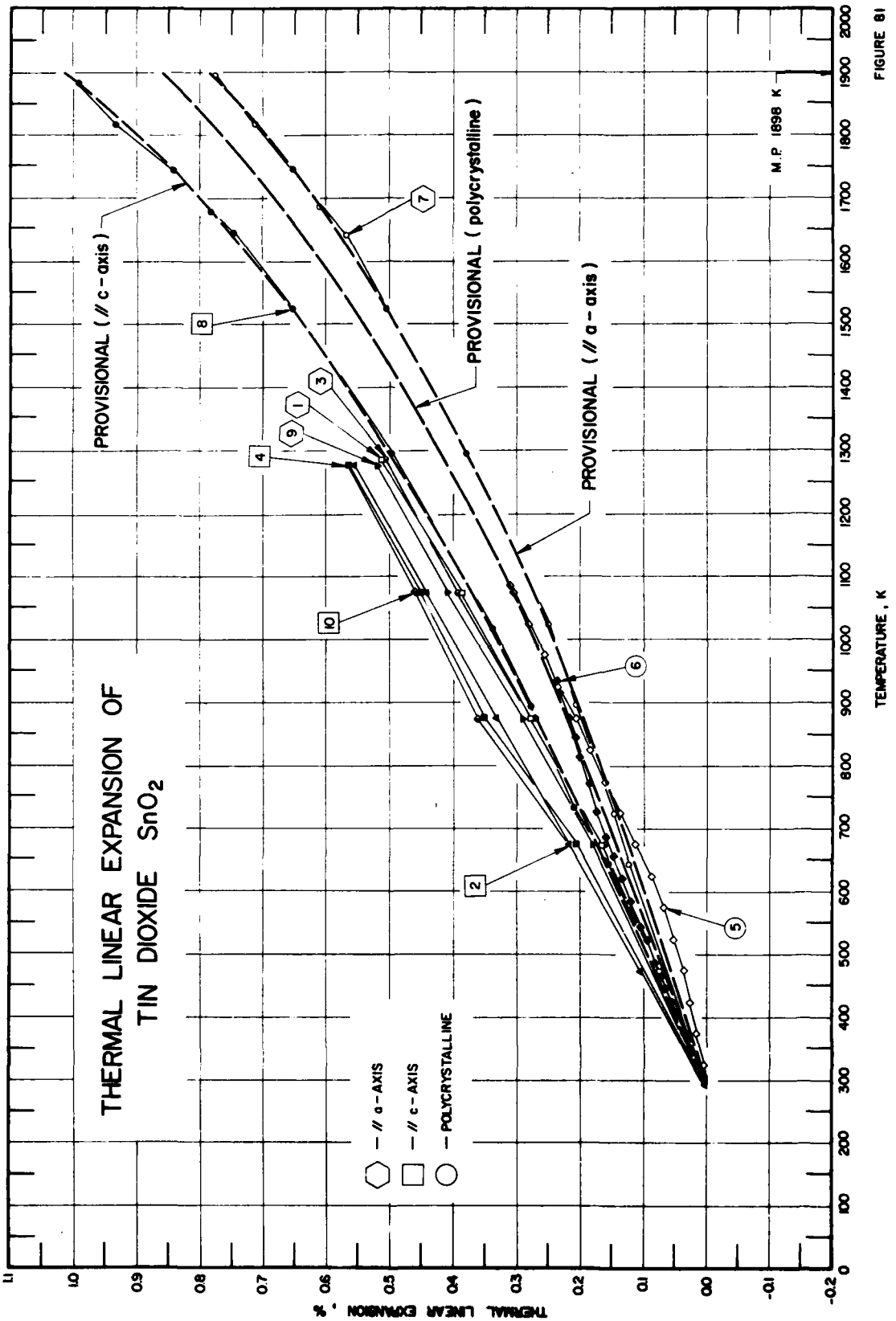

THERMAL LINEAR EXPANSION OF
TIN DIOXIDE SnO_2
PROVISIONAL (// c - axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// a - axis)
M.P 1898 K
— // a - AXIS
— // c - AXIS
— POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K

FIGURE 81

SPECIFICATION TABLE 81. THERMAL LINEAR EXPANSION OF TIN DIOXIDE SnO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	7	Kirchner, H.P., Gruver, R.M., and Walker, R.E.	1966	X	300-1282	Cassiterite	Commercially available specimen; crushed; expansion measured along a-axis of rutile structure; data from smoothed curve.
2	7	Kirchner, H.P., et al.	1966	X	292-1275	Cassiterite	The above specimen; expansion measured along c-axis of rutile structure; data from smoothed curve.
3	178	Kirchner, H.P., Scheetz, H.A., Brown, W.R., and Smyth, H.T.	1962	X	296-1273	Cassiterite	Specimen prepared by ball-milling SnO_2 for 4 hr, passed through 4 mesh standard screen, mixed with 15% binder (40 g carbowax 20 M, 20 cc of 2% methocel solution and 40 cc H_2O), dried at 383 K for 1 hr, passed through 16 mesh screen, pressed at 7000 psi into 1 in. disk, 0.25 in. thick, fired to 1273 K for 16 hr, cooled to room temperature for 30 min, and crushed to -325 mesh; expansion measured along a-axis; zero-point correction of 0.000% determined by graphical extrapolation.
4	178	Kirchner, H.P., et al.	1962	X	296-1273	Cassiterite	The above specimen; expansion measured along c-axis; zero-point correction of 0.000% determined by graphical extrapolation.
5	91	Hummel, F.A. and Henry, E.C.	1946		296-1084		Chemically pure specimen; data from smoothed curve; zero-point correction of 0.000% determined by graphical extrapolation.
6	179	Quirk, J. and Harman, C.G.	1954	L	293-933		99 SnO_2, 1 ZnO_2 chemically pure specimen; obtained from J. T. Baker in form of -200 mesh powder; dry ball milled 4 hr; compacted at >6000 psi, sintered at 1700 K for 2-3 hr; apparent porosity 0.4%.
7	645	Sakurai, T. and Takizawa, T.	1971	X	298-1898		Al_2O_3 chosen for reference material; specimen made by mixing Al_2O_3 with 50 vol.% SnO_2 of guaranteed grade pressing mixture into a slab 35 x 25 x 10 mm^3 and firing at 1350 C for several hr; lattice parameter measured along a-axis; 4.738 Å reported at 288 K; zero-point correction is -0.010%.
8	645	Sakurai, T. and Takizawa, T.	1971	X	298-1898		The above specimen; lattice parameter measured along c-axis; 3.188 Å reported at 288 K.
9	647	Merz, K.M., Brown, W.R., and Kirchner, H.P.	1962	X	293-1275		Powder specimen prepared by crushing disk in alumina mortar to pass 0.044 mm standard sieve; thermal expansion measured along a-axis.
10	647	Merz, K.M., et al.	1962	X	293-1275		The above specimen; thermal expansion measured along c-axis.

DATA TABLE 81. THERMAL LINEAR EXPANSION OF TIN DIOXIDE SnO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
300	0.003
473	0.073
672	0.167
873	0.277
1071	0.389
1282	0.512
CURVE 2	
292	0.000
473	0.106
673	0.219
874	0.331
1073	0.443
1275	0.558
CURVE 3	
296	0.000*
473	0.067
673	0.163
873	0.270
1073	0.390
1273	0.510
CURVE 4	
296	0.000*
473	0.105*
673	0.205
873	0.350
1073	0.450
1273	0.565
CURVE 5	
296	0.000*
323	0.005
372	0.017
422	0.025
473	0.036
523	0.051
573	0.069
622	0.089
672	0.112
722	0.136
772	0.160
823	0.185
873	0.209
924	0.233
975	0.257
1024	0.280
1074	0.305
1084	0.310
CURVE 6	
293	0.000*
307	0.008
323	0.016
348	0.023
373	0.033
379	0.036*
386	0.038*
406	0.045
423	0.054
434	0.059*
446	0.066
465	0.072
473	0.078*
489	0.081
502	0.087*
522	0.094
542	0.101
557	0.107*
573	0.115*
587	0.120
603	0.126*
620	0.133
637	0.139*
655	0.147
674	0.155*
684	0.160
697	0.162*
708	0.166*
728	0.173
748	0.179*
770	0.186
794	0.194*
812	0.200
825	0.202*
843	0.207
858	0.213*
877	0.218
894	0.224*
914	0.232
933	0.239
CURVE 7	
293	0.000*
641	0.121
723	0.144
897	0.206
1023	0.250
1297	0.380
1522	0.506
1640	0.569
1685	0.611
1746	0.654
1819	0.714
1895	0.777
CURVE 8	
293	0.000*
643	0.152
731	0.210
894	0.278
1019	0.338
1295	0.499
1522	0.654
1643	0.748
1677	0.781
1743	0.843
1819	0.934
1884	0.991
CURVE 9	
293	0.00*
473	0.08*
673	0.18
873	0.29
1075	0.41
1275	0.52
CURVE 10	
293	0.00*
473	0.11*
673	0.22*
873	0.36
1075	0.46
1275	0.57

* Not shown in figure.

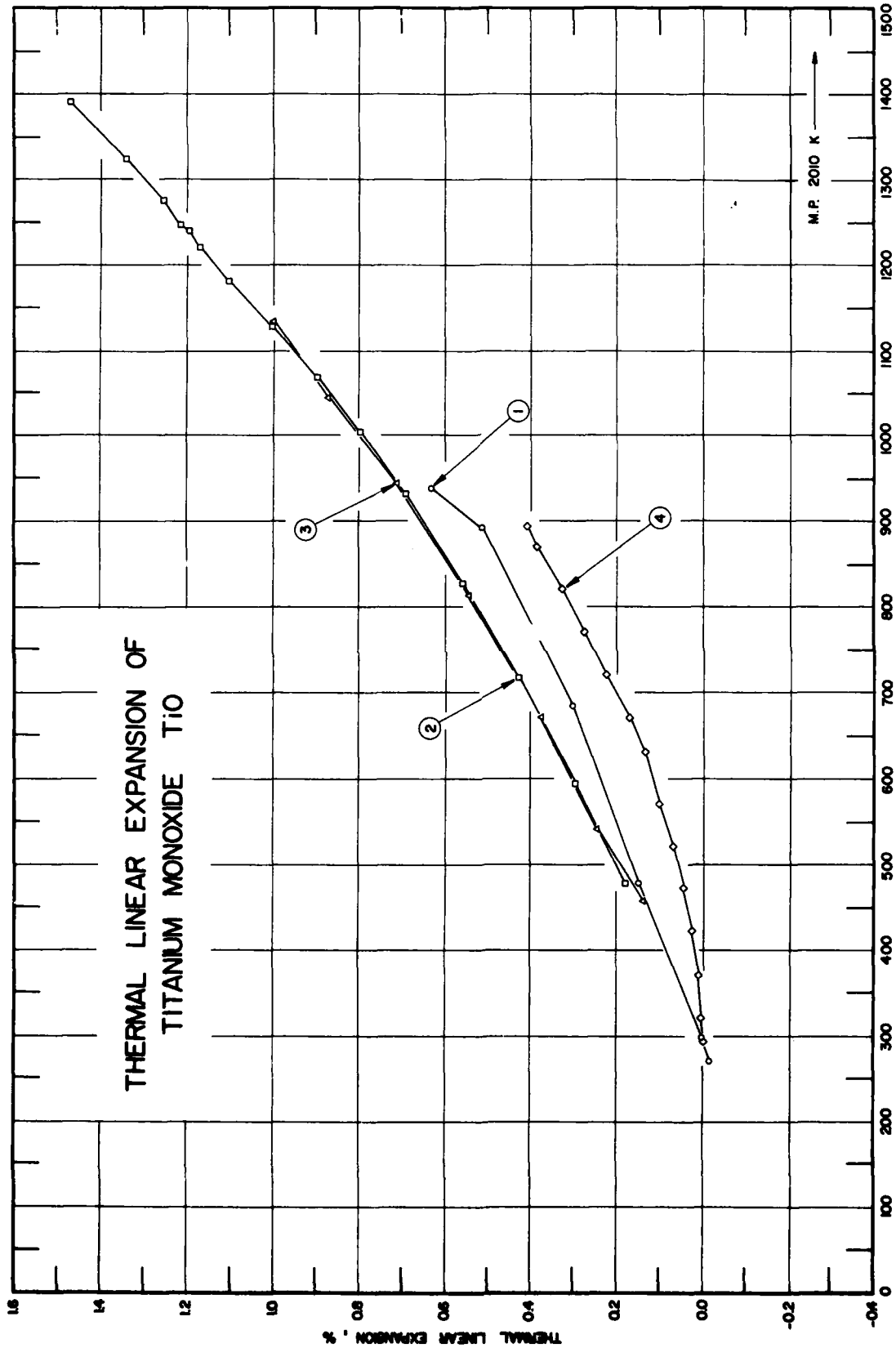

THERMAL LINEAR EXPANSION OF
TITANIUM MONOXIDE TiO
M.P. 2010 K
1
2
3
4
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 82

SPECIFICATION TABLE 82. THERMAL LINEAR EXPANSION OF TITANIUM MONOXIDE TiO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	10, 182	Mauer, F.A. and Bolz, L.H.	1955	X	273-994		Specimen prepared by mixing stoichiometrically c.p. grade TiO_2 of J. T. Baker Chemical Co. and Ti of Metal Hydrides Inc.; sintered at 1813 K for 1 hr in helium atmosphere; expansion measured in vacuum.
2	10, 182	Mauer, F.A. and Bolz, L. H.	1955	L	273-1390		Tube specimen; obtained from B.C. Weber of Wright Air Development Center; expansion measured in vacuum of 10^{-5} mm of Hg.
3	10, 182	Mauer, F.A. and Bolz, L.H.	1955	L	1133-459		The above specimen; expansion measured with decreasing temperature.
4	648	Taylor, A. and Doyle, N.J.	1970	X	273-895		Samples made by melting zone refined titanium metal 99.99% Ti and TiO_2 (99.99%) in an argon arc furnace to produce buttons weighing 10 g; homogenized by annealing for 2 days at 1500 C in a vacuum of 10^{-6} torr and quenched; data from smoothed curve.

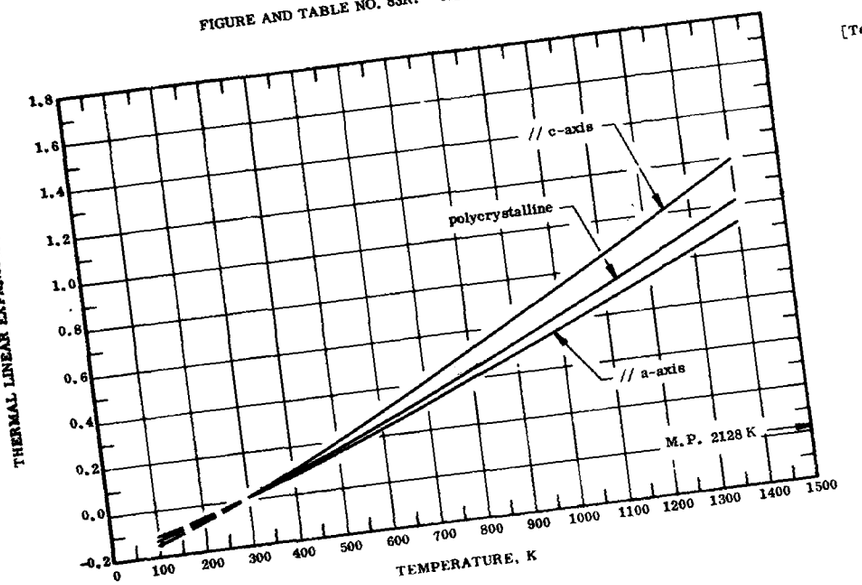
DATA TABLE 82. THERMAL LINEAR EXPANSION OF TITANIUM MONOXIDE TiO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
273	-0.017
298	0.005
479	0.150
685	0.303
891	0.516
994	0.631
CURVE 2	
273	-0.018
299	0.006
479	0.181
595	0.299
719	0.429
829	0.561
931	0.691
1005	0.799
1069	0.899
1128	1.004
1221	1.169
CURVE 2 (cont.)	
1242	1.194
1247	1.218
1278	1.258
1322	1.343
1390	1.472
CURVE 3	
1133	1.009
1045	0.869
943	0.714
815	0.544
672	0.377
543	0.244
459	0.140
CURVE 4	
273	-0.002*
293	0.000
CURVE 4 (cont.)	
323	0.005
373	0.012
423	0.024
473	0.043
523	0.071
573	0.102
623	0.138
673	0.178
723	0.224
773	0.276
823	0.328
873	0.385
895	0.409

*Not shown in figure.

FIGURE AND TABLE NO. 83R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF TITANIUM DIOXIDE TiO_2



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	// c-axis $\Delta L/L_0$	// a-axis $\Delta L/L_0$	polycrystalline $\Delta L/L_0$	polycrystalline α
100	-0.155†	-0.120†	-0.130†	6.5
150	-0.121†	-0.093†	-0.100†	6.8
200	-0.080†	-0.062†	-0.070†	7.1
250	-0.038†	-0.030†	-0.032†	7.3
293	0.000	0.000	0.000	7.5
400	0.100	0.077	0.083	8.0
500	0.197	0.150	0.165	8.4
600	0.300	0.230	0.251	8.8
700	0.410	0.308	0.341	9.1
800	0.520	0.400	0.435	9.3
900	0.630	0.480	0.530	9.5
1000	0.740	0.570	0.623	9.7
1100	0.855	0.654	0.721	9.8
1200	0.970	0.745	0.819	9.9
1300	1.083	0.836	0.918	10.5
1400	1.200	0.927	1.020	11.0

† Provisional values.

REMARKS

The recommended values for the axial thermal expansion are based on the data for pure samples. The values for the polycrystalline sample are calculated from the axial values. This result agrees well with most of the experimental data. These values are considered accurate to within ±3% at temperatures above 293 K and ±7% at temperatures below 293 K and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -0.232 + 6.796 \times 10^{-4} T + 4.182 \times 10^{-7} T^2 - 1.256 \times 10^{-10} T^3$

// a-axis: $\Delta L/L_0 = -0.181 + 5.478 \times 10^{-4} T + 2.576 \times 10^{-7} T^2 - 5.944 \times 10^{-11} T^3$

polycrystalline: $\Delta L/L_0 = -0.198 + 5.906 \times 10^{-4} T + 3.133 \times 10^{-7} T^2 - 8.266 \times 10^{-11} T^3$

The tabulated values for the coefficeint of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±7%.

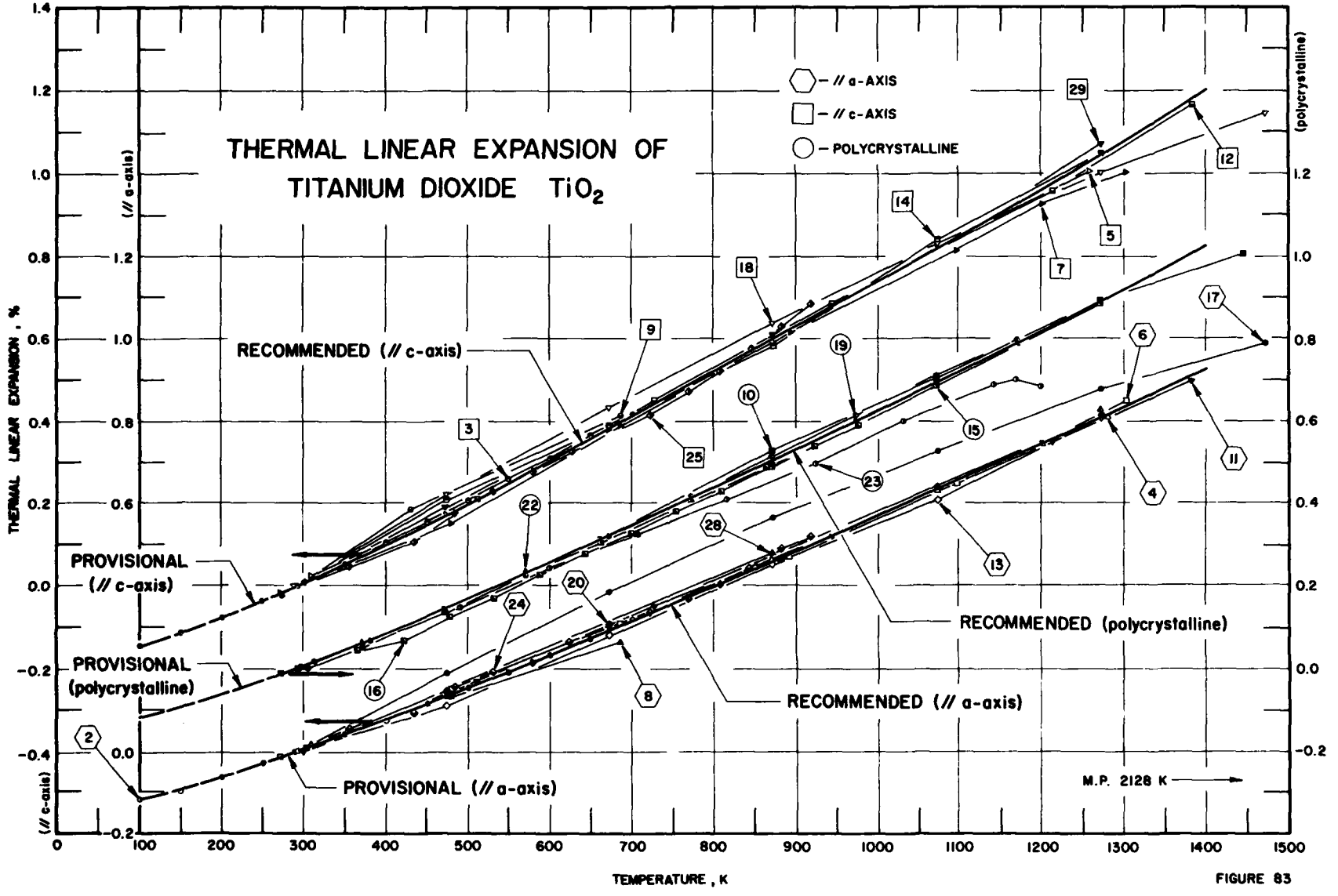

THERMAL LINEAR EXPANSION OF
TITANIUM DIOXIDE TiO_2
⬡ – // a-AXIS
□ – // c-AXIS
○ – POLYCRYSTALLINE
RECOMMENDED (// c-axis)
PROVISIONAL
(// c-axis)
PROVISIONAL
(polycrystalline)
PROVISIONAL (// a-axis)
RECOMMENDED (polycrystalline)
RECOMMENDED (// a-axis)
M.P. 2128 K
THERMAL LINEAR EXPANSION , %
(// a-axis)
(// c-axis)
(polycrystalline)
TEMPERATURE , K
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
22
23
24
25
28
29

FIGURE 83

SPECIFICATION TABLE 83. THERMAL LINEAR EXPANSION OF TITANIUM DIOXIDE TiO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	298-1723		Specimen 0.5 x 0.5 in. cross section, 7 in. long; coarse fused grain; ends sawed at rake and to point.
2	180	Kirby, R.K.	1967	I	100-700		≤0.1 impurities; single crystal specimen; obtained from National Lead Co.; grown by Verneuil flame fusion technique; cut with diamond saw, ground faces parallel and optically flat; density 4.24 g cm^{-3}; expansion measured along a-axis in helium atm with pressure of 2 torr.
3	180	Kirby, R.K.	1967	I	100-700		The above specimen; expansion measured along c-axis.
4	7	Kirchner, H.P., Gruver, R.M. and Walker, R.E.	1966	X	311-1281		Commercially available specimen; crushed; expansion measured along a-axis; data from smoothed curve.
5	7	Kirchner, H.P., et al.	1966	X	310-1259		The above specimen; expansion measured along c-axis; data from smoothed curve.
6	10	Mauer, F.A. and Bolz, L.H.	1955	X	273-1303	Rutile	C.P. grade specimen; obtained from J.T. Baker Chemical Co.; fired to 1700 C in oxidizing atm to tive only tetragonal rutile phase; sintered at 1200 C; expansion measured along a-axis in helium atm; zero-point correction of -0.016% determined by graphical interpolation.
7	10	Mauer, F.A. and Bolz, L.H.	1955	X	273-1303	Rutile	The above specimen; expansion measured along c-axis; zero-point correction of -0.020% determined by graphical interpolation.
8	10	Mauer, F.A. and Bolz, L.H.	1955	X	273-686	$TiO_{1.97}$ Black rutile	0.601 O deficiency; obtained from Dr. B.C. Weber of Wright Air Development Center; prepared by heating TiO_2 in vacuum of 1538 C with no soak; powder sintered at 1200 C in helium atm, expansion measured along a-axis in helium atm; zero-point correction of -0.014% determined by graphical interpolation.
9	10	Mauer, F.A. and Bolz, L.H.	1955	X	273-686	$TiO_{1.97}$ Black rutile	The above specimen; expansion measured along c-axis; zero-point correction of -0.021% determined by graphical interpolation.
10	10	Mauer, F.A. and Bolz, L.H.	1955	L	273-1448		Tube specimen, 1.257 in. long; prepared by Dr. B.C. Weber of Wright Air Development Center; expansion measured in air atm; zero-point correction of -0.011%.
11	61	Grain, C.F. and Campbell, W.J.	1962	X	299-1383	Rutile	99.9 pure specimen; fired at 1200 C 6 hrs; cooled; spread on platinum-coated alumina holder; expansion measured along a-axis.
12	61	Grain, C.F. and Campbell, W.J.	1962	X	299-1383	Rutile	The above specimen, expansion measured along c-axis.
13	105	Sarver, J.F.	1963	X	473-1273	Titanox, T.G.	<0.1 WO_3, 0.04 SiO_2, <0.01 CaO, 0.008 Nb, 0.007 Sb_2O_3, 0.006 Fe_2O_3, 0.001-0.002 Pb, 0.001 V, 0.0005 Cu, 0.0004 Cr, 0.00005 Mn; specimen obtained from Titanium Pigment Corp.; prepared by ball milling TiO_2 for 4 hrs, passed through 4 mesh standard screen, mixed with 15% binder (40 g Carbowax 20M, 20cc of 2% methocel solution) and 40cc H_2O, dried at 110 C 1 hr, passed through 16 mesh screen, pressed at 7000 psi into 1 in. disk 0.25 in. thick, fired, cooled to room temp in 30 min, and crushed to -325 mesh; expansion measured along a-axis.
14	105	Sarver, J.F.	1963	X	473-1273	Titanox, T.G.	The above specimen; expansion measured along c-axis.
15	105	Sarver, J.F.	1963	L	298-1273		Aggregated specimen 1 x 1 x 10 cm; fired at 1473 K 6 hrs.
16	181	Smoke, E.Y., Rooda, J., Sirkis, M.D., Holsberg, P.J., Melony, D.A. and Choa, C.	1960	L	366-977		Pure specimen; fired at 1750 K; bulk density 4.05 g cm^{-3}.

* Not shown in figure.

SPECIFICATION TABLE 83. THERMAL LINEAR EXPANSION OF TITANIUM DIOXIDE TiO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
17	74	Beals, R.J. and Cook, R.L.	1957	X	289-1473	Rutile	Reagent grade, tetragonal structured powder specimen; expansion measured along a-axis.
18	74	Beals, R.J. and Cook, R.L.	1957	X	289-1473	Rutile	The above specimen; expansion measured along c-axis.
19	183	Ricker, R.W. and Hummel, F.A.	1951	L	305-1273	No. 21	Specimen calcined at 1373 K 1.5 hrs; then heat-treated at 1813 K 2 hrs and at 1773 K 8 hrs.
20	29	Merz, K.M., Kirchner, H.P. and Smyth, H.T.	1960	X	297-1273		Reagent grade specimen; expansion measured along a-axis.
21*	29	Merz, K.M., et al.	1960	X	297-1273		The above specimen; expansion measured along c-axis.
22	263	Bunting, E.N., Shelton, G.R. and Creamer, A.S.	1947	I	373-1173	TMO Rutile	98.7 TiO_2, 0.25 SiO_2, 0.2 Al_2O_3; rutile crystal, disk specimen; 0.25-1 in. dia, 0.125 in. thick; powder dry-pressed at 20 000 psi; heated at 1000 C in electrical furnace.
23	31	Mason, C.R., Walton, J.D., Bowen, M.D., Teague, W.T. and Murphy, C.A.	1960	L	315-1199	No. 1169-3-12	Arc-sprayed tubular specimen; 0.953 cm I.D., 1.27 cm O.D., 3.8-5 cm long; prepared by spraying 20-50 μ particles onto brass tube, then removing brass by leaching in dilute nitric acid; density 3.17 g cm^{-3}; zero-point correction of 0.017% determined by graphical extrapolation.
24	185	Krishna Rao, K.V., Naidu, S.V.N. and Iyengar, L.	1970	X	303-918	Rutile	Mineral specimen; powdered and pasted to quartz rod; expansion measured with Cu Kα radiation along a-axis.
25	185	Krishna Rao, K.V., et al.	1970	X	303-918	Rutile	The above specimen; expansion measured along c-axis.
26*	185	Krishna Rao, K.V., et al.	1970	X	301-985	Anatase	Pure specimen of synthetic anatase; similar to the above specimen; expansion measured along a-axis.
27*	185	Krishna Rao, K.V., et al.	1970	X	301-985	Anatase	The above specimen; expansion measured along c-axis.
28	647	Merz, K.M., Brown, W.R., and Kirchner, H.P.	1962	X	300-1273		Specimen composition analysis 0.1 WO_3, 0.01 CaO, 0.04 SiO_2, 0.008 Nb, 0.007 Sb_2O_3, 0.006 Fe_2O_3, 10-20 ppm Pb, 10 ppm V, 5 ppm Cu, 4 ppm Cr, 0.5 ppm Mn; obtained from Titanox TG of the Titanium Pigment Corp.; powder specimen prepared by crushing the disks in alumina mortar to pass 0.044-mm standard sieve; thermal expansion measured along a-axis; zero-point correction 0.01% determined by graphical extrapolation.
29	647	Merz, K.M., et al.	1962	X	293-1273		The above specimen; thermal expansion measured along c-axis; zero-point correction 0.01%.

* Not shown in figure.

DATA TABLE 83. THERMAL LINEAR EXPANSION OF TITANIUM DIOXIDE TiO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
298	0.004
573	0.199
873	0.447
1173	0.722
1473	1.027
1723	1.301
CURVE 2	
100	-0.1158
150	-0.0920
200	-0.0626
250	-0.0299
293	0.0000
300	0.0050
350	0.0417
400	0.0795
450	0.1179
500	0.1568
550	0.1966
600	0.2372
650	0.2785
700	0.3202
CURVE 3	
100	-0.1439
150	-0.1161
200	-0.0797
250	-0.0383
293	0.0000
300	0.0064
350	0.0537
400	0.1029
450	0.1535
500	0.2052
550	0.2579
600	0.3114
650	0.3653
700	0.4193
CURVE 4	
311	0.020
473	0.136
673	0.300
CURVE 4 (cont.)	
873	0.467
1073	0.638
1281	0.816
CURVE 5	
310	0.023
473	0.172
672	0.380
873	0.596
1073	0.823
1259	1.031
CURVE 6	
273	-0.016
304	0.006
479	0.150
685	0.308
891	0.470
1097	0.650
1200	0.742
1303	0.853
CURVE 7	
273	-0.020
304	0.007
479	0.149
685	0.389
891	0.612
1097	0.815
1200	0.926
1303	1.058
CURVE 8	
273	-0.014*
303	0.006*
479	0.134
686	0.267
CURVE 9	
273	-0.021
303	0.009*
CURVE 9 (cont.)	
479	0.188
686	0.411
CURVE 10	
273	-0.011
293	0.000
473	0.136
663	0.312
873	0.527
1073	0.704
1273	0.892
1448	1.056
CURVE 11	
299	0.00
513	0.17
728	0.35
943	0.52
1213	0.75
1383	0.90
CURVE 12	
299	0.00*
513	0.21
728	0.45
943	0.68
1213	0.96
1383	1.17
CURVE 13	
473	0.112
673	0.282
873	0.452
1073	0.612
1273	0.812
CURVE 14	
473	0.207
673	0.387
873	0.587
1073	0.842
1273	1.052
CURVE 15	
298	0.004
473	0.139
673	0.304
873	0.489
1073	0.684
1273	0.884
CURVE 16	
366	0.0422
422	0.0630
477	0.123
533	0.170
588	0.225
644	0.277
699	0.328
755	0.382
810	0.431
866	0.488
922	0.538
977	0.591
CURVE 17	
289	0.000
473	0.192
673	0.385
873	0.564
1073	0.731
1273	0.879
1473	0.988
CURVE 18	
289	0.000*
473	0.218*
673	0.432
873	0.637
1073	0.832
1273	1.009
1473	1.148
CURVE 19	
305	0.000
373	0.050
CURVE 19 (cont.)	
473	0.137*
573	0.225
673	0.319
773	0.416
873	0.514
973	0.612
1073	0.709
1173	0.796
1273	0.888*
CURVE 20	
297	0.000
473	0.139
673	0.301
873	0.462*
1073	0.638
1273	0.814
CURVE 21*	
297	0.000
473	0.172
673	0.379
873	0.595
1073	0.818
1273	1.051
CURVE 22	
373	0.06
473	0.14*
573	0.23
673	0.32*
773	0.41
873	0.50
973	0.60
1073	0.69
1173	0.79
CURVE 23	
315	0.017
381	0.067
490	0.147
599	0.240
CURVE 23 (cont.)	
707	0.324
816	0.411
924	0.495
1033	0.599
1142	0.684
1170	0.699
1199	0.680
CURVE 24	
303	0.008*
357	0.056
434	0.095
483	0.153
531	0.192
579	0.213
627	0.266
674	0.298*
722	0.335
770	0.366
807	0.405
844	0.444
881	0.492
918	0.520
CURVE 25	
303	0.007*
357	0.048
434	0.109
483	0.177
531	0.227
579	0.275
627	0.329
674	0.379*
722	0.416
770	0.471
807	0.521
844	0.575
881	0.626
918	0.680
CURVE 26*	
301	0.004*
357	0.030

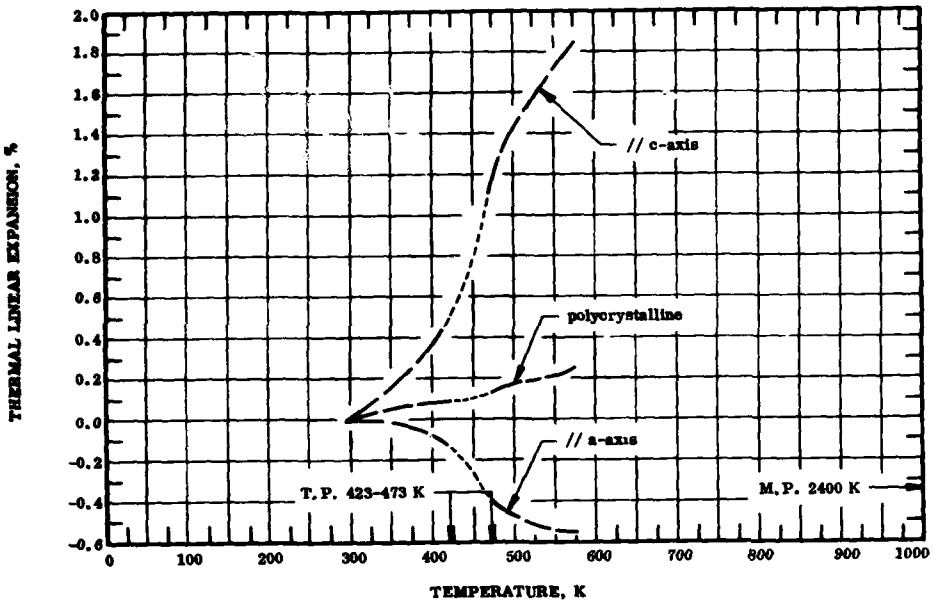
* Not shown in figure.

DATA TABLE 83. THERMAL LINEAR EXPANSION OF TITANIUM DIOXIDE TiO_2 (continued)

T	$\Delta L/I_0$
CURVE 26 (cont.)*	
434	0.059
483	0.083
531	0.107
579	0.133
627	0.168
722	0.210
770	0.252
807	0.276
844	0.313
881	0.334
918	0.384
952	0.408
985	0.437
CURVE 27*	
301	0.006*
357	0.050*
434	0.117*
483	0.165
531	0.215
579	0.249
627	0.310
722	0.432
770	0.481
807	0.559
844	0.649
881	0.691
918	0.773
952	0.837
985	0.881
CURVE 28	
300	0.01*
473	0.15*
673	0.31*
873	0.48
1073	0.65*
1273	0.83
CURVE 29	
293	0.00*
473	0.19
673	0.39*
873	0.61
1073	0.82*
1273	1.07

* Not shown in figure.

FIGURE AND TABLE NO. 84R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF DITITANIUM TRIOXIDE Ti_2O_3



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Hexagonal Structure			
	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	9.0
325	0.083	0.000	0.130	9.0
350	0.163	-0.007	0.050	7.0
375	0.260	-0.026	0.068	5.4
400	0.375	-0.064	0.081	4.3
425	0.538†	-0.138†	0.088†	1.6
450	0.83†	-0.28†	0.090†	
473	1.22†	-0.41†	0.133†	
500	1.44	-0.47	0.167	
525	1.58	-0.51	0.187	
550	1.73	-0.54	0.217	
575	1.85	-0.55	0.250	

† Values in transition range.

REMARKS

The provisional values for the axial thermal expansion indexed in hexagonal structure are based on data measured by x-ray method. The values for the polycrystalline sample are calculated from the axial values. There is no structure change to account for the abrupt changes in lattice parameters of trigonal unit cell in the transition temperature range 423-473 K. All the experimental lattice parameters were indexed in hexagonal structure. These values are considered accurate to within ±7% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -0.390 + 3.330 \times 10^{-2}\,T - 1.000 \times 10^{-4}\,T^2 + 1.091 \times 10^{-7}\,T^3$ (293-425 K)

// a-axis: $\Delta L/L_0 = 3.608 - 3.387 \times 10^{-2}\,T + 1.060 \times 10^{-4}\,T^2 - 1.108 \times 10^{-7}\,T^3$ (293-425 K)

polycrystalline: $\Delta L/L_0 = -1.172 + 7.846 \times 10^{-3}\,T - 1.687 \times 10^{-5}\,T^2 + 1.266 \times 10^{-8}\,T^3$ (293-425 K)

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

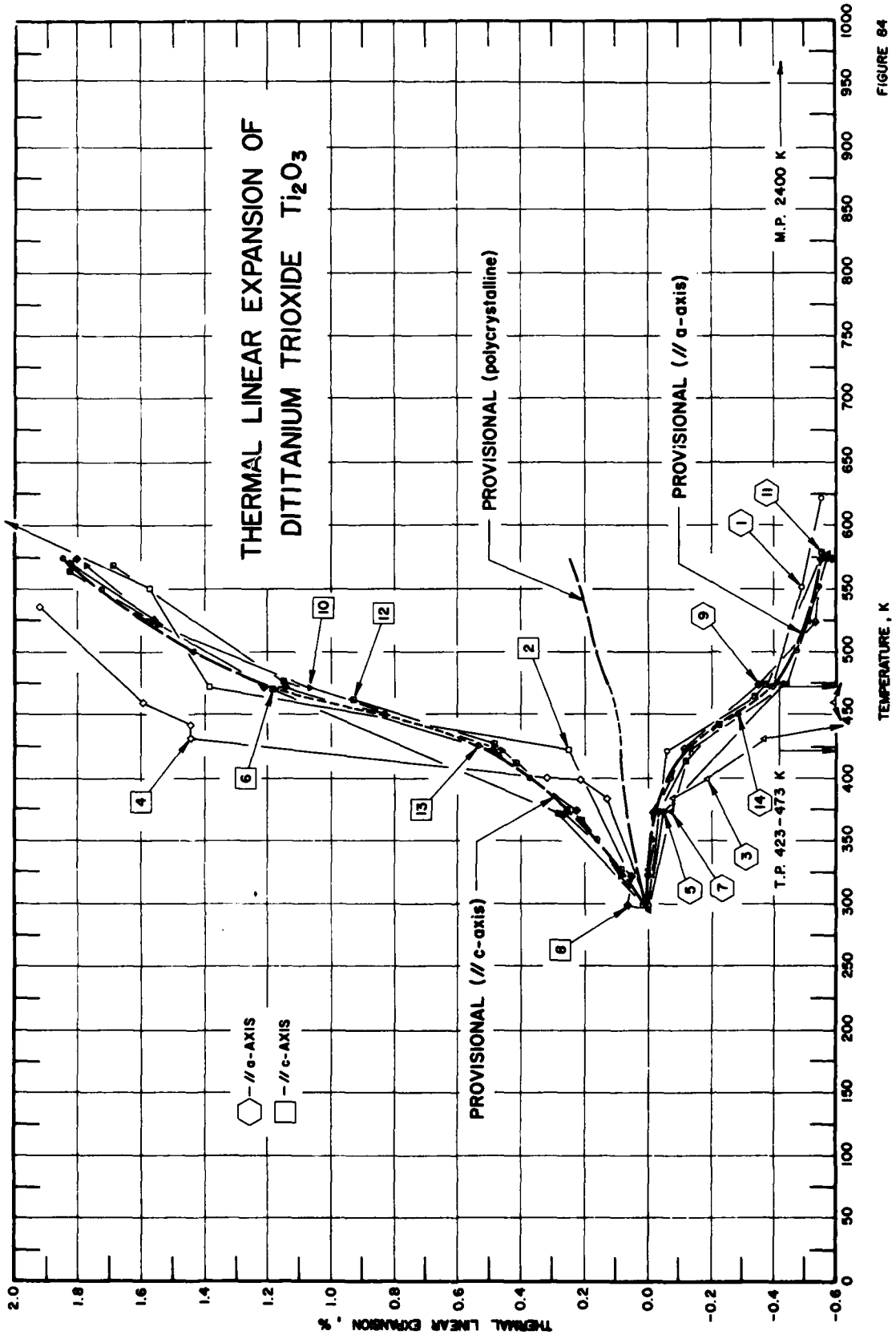

THERMAL LINEAR EXPANSION OF
DITITANIUM TRIOXIDE Ti_2O_3
PROVISIONAL (polycrystalline)
PROVISIONAL (// a-axis)
PROVISIONAL (// c-axis)
M.P. 2400 K
T.P. 423 – 473 K
// a-AXIS
// c-AXIS
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K

FIGURE 84

SPECIFICATION TABLE 84. THERMAL LINEAR EXPANSION OF DITITANIUM TRIOXIDE Ti_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	335	Pearson, A.D.	1958	X	297-621		Specimen prepared by reduction of TiO_2 with stoichiometric amount of Ti metal, $Ti + 3\ TiO_2 \rightarrow 2\ Ti_2O_3$, in solid state; crystal structure is of α-Al_2O_3 type with trigonal (also known as rhombohedral) unit cell; there is no change in crystal structure to account for the transition near 473 K in Ti_2O_3, but lattice parameters of unit cell change rapidly between 433 and 473 K; the unit cell pattern was indexed by author in hexagonal system for ease of computation, and lattice parameters refined by least squares method; expansion measured along a-axis; a_{hex} reported at 297 K is 5.151 Å; 5.151 Å at 293 K determined by graphical extrapolation.
2	335	Pearson, A.D.	1958	X	297-621		The above specimen; expansion measured along c-axis; c_{hex} reported at 297 K is 13.620 Å; 13.618 Å at 293 K determined by graphical extrapolation.
3	186	Rao, C.N.R., Lochman, R.E., and Honig, J.M.	1968	X	294-537		High purity Ti_2O_3 prepared by arc melting TiO_2 and Ti (of 99.99+ purity) in proper stoichiometric proportions under argon atm; data show abrupt changes in lattice parameters with temperature in range 390-470 K; trigonal unit cell parameters indexed by authors in hexagonal system; expansion measured along a-axis; averaged a_{hex} value reported at 294 K is 5.1582 Å.
4	186	Rao, C.N.R., et al.	1968	X	294-537		The above specimen; expansion measured along c-axis; averaged c_{hex} value reported at 294 K is 13.627 Å.
5	646	Eckert, L.J. and Bradt, R.C.	1973	X	293-474		Ti_2O_3 prepared by mixing titanium metal (Ti) and rutile (TiO_2) in molar ratio 1:3; mixture pelletized placed in quartz tube and fired at 1150 C for 20 hr; lattice parameter measured along a-axis; 5.139 Å reported at 293 K.
6	646	Eckert, L.J. and Bradt, R.C.	1973	X	293-564		The above specimen; lattice parameter measured along c-axis; 13.657 Å reported at 293 K.
7	646	Eckert, L.J. and Bradt, R.C.	1973	X	293-578		Similar to the above specimen; lattice parameter measured along a-axis.
8	646	Eckert, L.J. and Bradt, R.C.	1973	X	293-575		The above specimen; lattice parameter measured along c-axis.
9	646	Eckert, L.J. and Bradt, R.C.	1973	X	293-574		Similar to the above specimen; lattice parameter measured along a-axis.
10	646	Eckert, L.J. and Bradt, R.C.	1973	X	293-570		The above specimen; lattice parameter measured along c-axis.
11	646	Eckert, L.J. and Bradt, R.C.	1973	X	293-578		Similar to the above specimen; lattice parameter measured along a-axis.
12	646	Eckert, L.J. and Bradt, R.C.	1973	X	293-569		The above specimen; lattice parameter measured along c-axis.

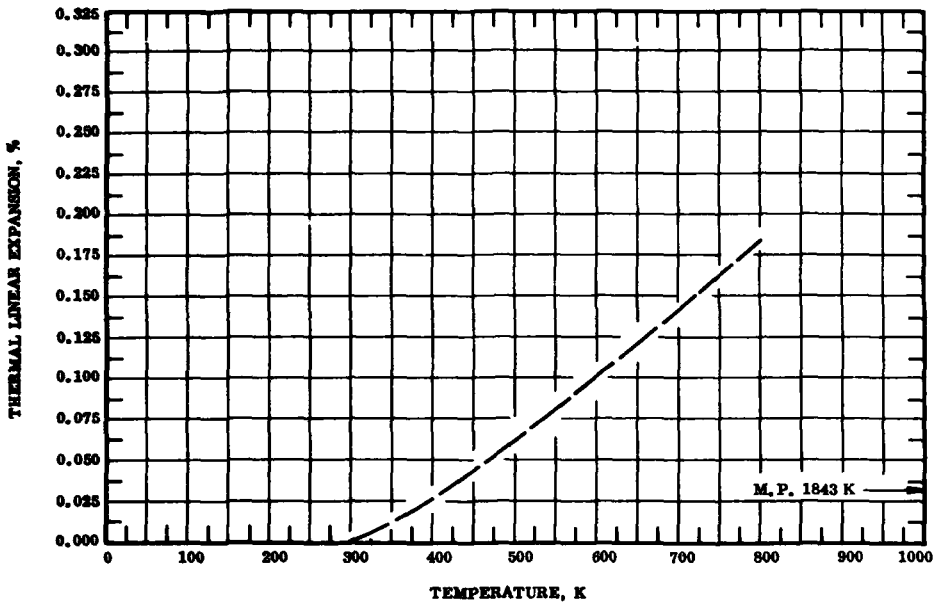
DATA TABLE 84. THERMAL LINEAR EXPANSION OF DITITANIUM TRIOXIDE Ti_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
297	0.000
422	-0.058
471	-0.388
550	-0.485
621	-0.544
CURVE 2	
297	0.015
422	0.257
471	1.388
550	1.579
621	2.269
CURVE 3	
294	0.000
384	-0.076
399	-0.189
432	-0.366
441	-0.620
458	-0.582
537	-0.696
CURVE 4	
294	0.000
384	0.139
399	0.213
400	0.323
432	1.446
441	1.453
458	1.599
537	1.923
CURVE 5	
293	0.000*
299	-0.004*
374	-0.043
474	-0.428
CURVE 6	
293	0.000*
297	0.015*
372	0.286
470	1.186
564	1.823
CURVE 7	
293	0.000*
299	-0.023*
328	0.000
374	-0.029
374	-0.066
423	-0.138
474	-0.393
474	-0.438
525	-0.508
575	-0.566
578	-0.572
CURVE 8	
293	0.000*
297	0.066
322	0.051
372	0.264
375	0.227
422	0.491
471	1.150
471	1.215
526	1.560
570	1.823
575	1.801
CURVE 9	
293	0.000*
324	0.000
374	-0.014
424	-0.107
473	-0.348
524	-0.527
574	-0.549
574	-0.588
CURVE 10	
293	0.000*
323	0.088
371	0.220*
422	0.461
471	1.076
521	1.552
570	1.772
CURVE 11	
293	0.000*
325	0.014*
374	-0.004*
414	-0.117
424	-0.101*
442	-0.220
463	-0.333
474	-0.370
578	-0.543
CURVE 12	
293	0.000*
328	0.088
366	0.212
411	0.417
427	0.491
462	0.937
476	1.157
569	1.691

* Not shown in figure.

FIGURE AND TABLE NO. 85R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF TUNGSTEN DIOXIDE WO_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	2.6
350	0.016	2.9
400	0.031	3.2
450	0.047	3.4
500	0.065	3.6
550	0.083	3.8
600	0.102	3.9
650	0.122	4.0
700	0.142	4.1
750	0.163	4.1
800	0.183	4.1

REMARKS

The provisional values are based on the data for pure samples and are considered accurate to within ±7%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.044 + 2.307 \times 10^{-5} T + 4.911 \times 10^{-7} T^2 - 2.069 \times 10^{-10} T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

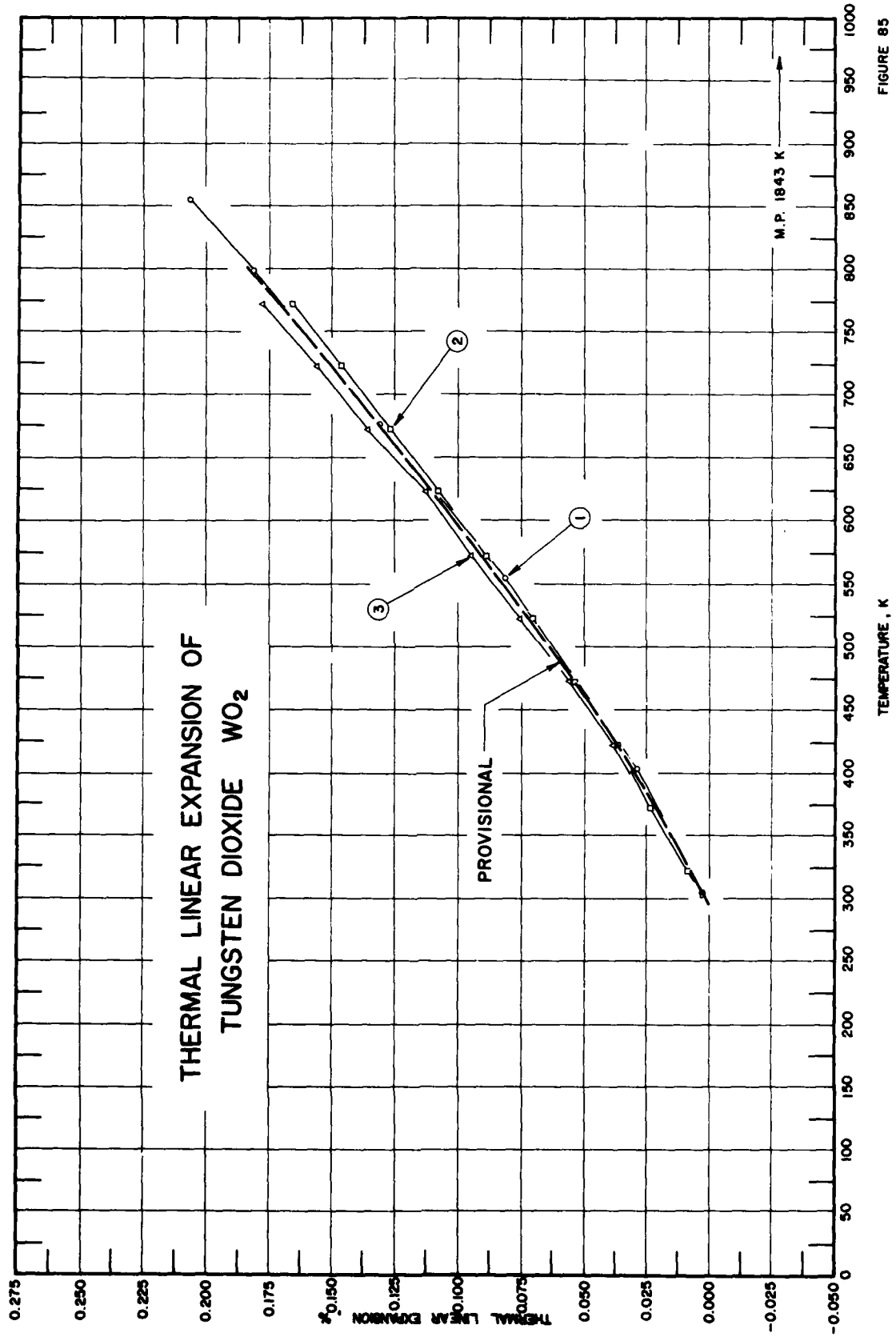

THERMAL LINEAR EXPANSION OF
TUNGSTEN DIOXIDE WO_2
PROVISIONAL
M.P. 1843 K
1
2
3
THERMAL LINEAR EXPANSION %
TEMPERATURE, K
0.275
0.250
0.225
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
-0.025
-0.050
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 85

SPECIFICATION TABLE 85. THERMAL LINEAR EXPANSION OF TUNGSTEN DIOXIDE WO_2

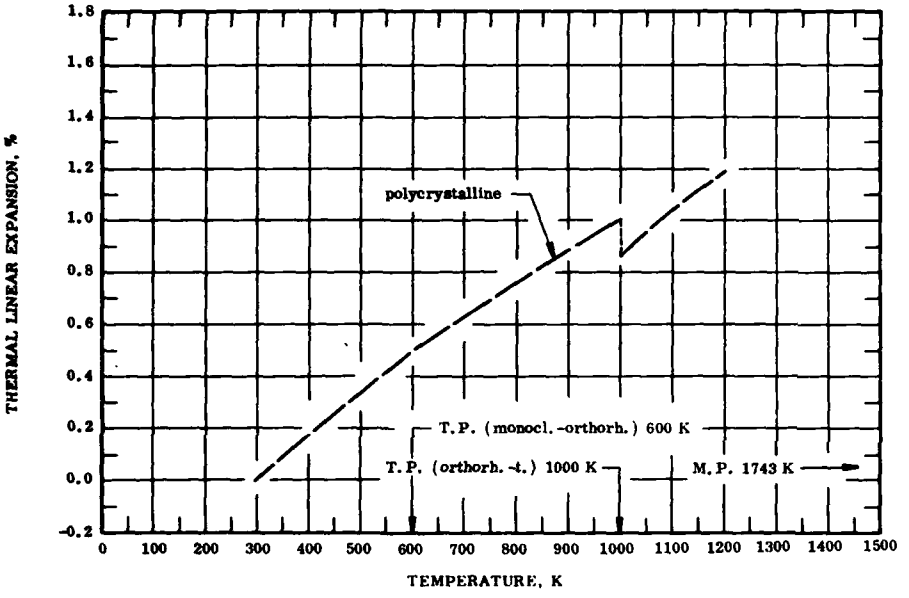
Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	187	Takamori, T. and Tomozawa, M.	1965	L	304-855		Rod specimen; degreased, heated at 1373 K for 15 min, polished, preoxidized, and sheathed with glass, fused to glass; expansion of interplayer specimen existing between glass and tungsten measured; zero-point correction of 0.054% determined by graphical extrapolation.
2	188	Takamori, T.	1964	L	303-773		95^+ pure; polycrystalline specimen; 5 x 5 mm cross section, 55 mm long; prepared by stoichiometrically mixing of WO_3 of Wako Pure Chemical Industries and metallic W powder of Tokyo Tungsten Co., heated to 1223 K for 40 hr in nitrogen atm, crushed, dry-pressed, sintered; heating rate 2.5 - 3 C per min; expansion measured in air atm; zero-point correction of 0.003% determined by graphical extrapolation.
3	188	Takamori, T.	1964	L	303-773		The above specimen; expansion measured on second test; zero-point correction of 0.003% determined by graphical extrapolation.

DATA TABLE 85. THERMAL LINEAR EXPANSION OF TUNGSTEN DIOXIDE WO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
304	0.003
403	0.029
553	0.082
677	0.131
798	0.182
855	0.207
CURVE 2	
303	0.003
323	0.009
373	0.023
423	0.037
473	0.054
523	0.071
573	0.089
623	0.108
673	0.127
723	0.147
773	0.167
CURVE 3	
303	0.003
323	0.008
373	0.023
423	0.039
473	0.057
523	0.076
573	0.095
623	0.116
673	0.136
723	0.157
773	0.178

FIGURE AND TABLE NO. 86R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF TUNGSTEN TRIOXIDE WO_3



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	16.4
350	0.094	16.4
400	0.176	16.4
450	0.258	16.3
500	0.339	16.3
550	0.420	16.2
600†	0.500	16.1
600	0.500	13.4
650	0.564	13.1
700	0.629	12.8
750	0.693	12.7
800	0.756	12.6
850	0.819	12.6
900	0.883	12.7
950	0.947	12.9
1000‡	1.012	13.2
1000‡	0.869	17.0
1050	0.954	16.6
1100	1.035	16.2
1150	1.115	15.6
1200	1.191	14.9

† Transition temperature from monoclinic to orthorhombic structure.
‡ Transition temperature from orthorhombic to tetragonal structure.

REMARKS

The provisional values for the polycrystalline sample are based on the data reported in curves 11 to 14 and are considered accurate to within ±7%. A rather gradual expansion changes observed at transition temperature 600 K and a remarkable contraction at transition temperature 1000 K. These values are represented approximately by the following equations:

$$\Delta L/L_0 = -0.479 + 1.619 \times 10^{-3}\,T + 8.70 \times 10^{-6}\,T^2 - 1.051 \times 10^{-10}\,T^3 \qquad (293\text{-}600\ K)$$

$$\Delta L/L_0 = -0.572 + 2.441 \times 10^{-3}\,T - 1.450 \times 10^{-6}\,T^2 + 5.942 \times 10^{-10}\,T^3 \qquad (600\text{-}1000\ K)$$

$$\Delta L/L_0 = -0.424 + 1.591 \times 10^{-4}\,T + 1.860 \times 10^{-6}\,T^2 - 7.259 \times 10^{-10}\,T^3 \qquad (1000\text{-}1200\ K)$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

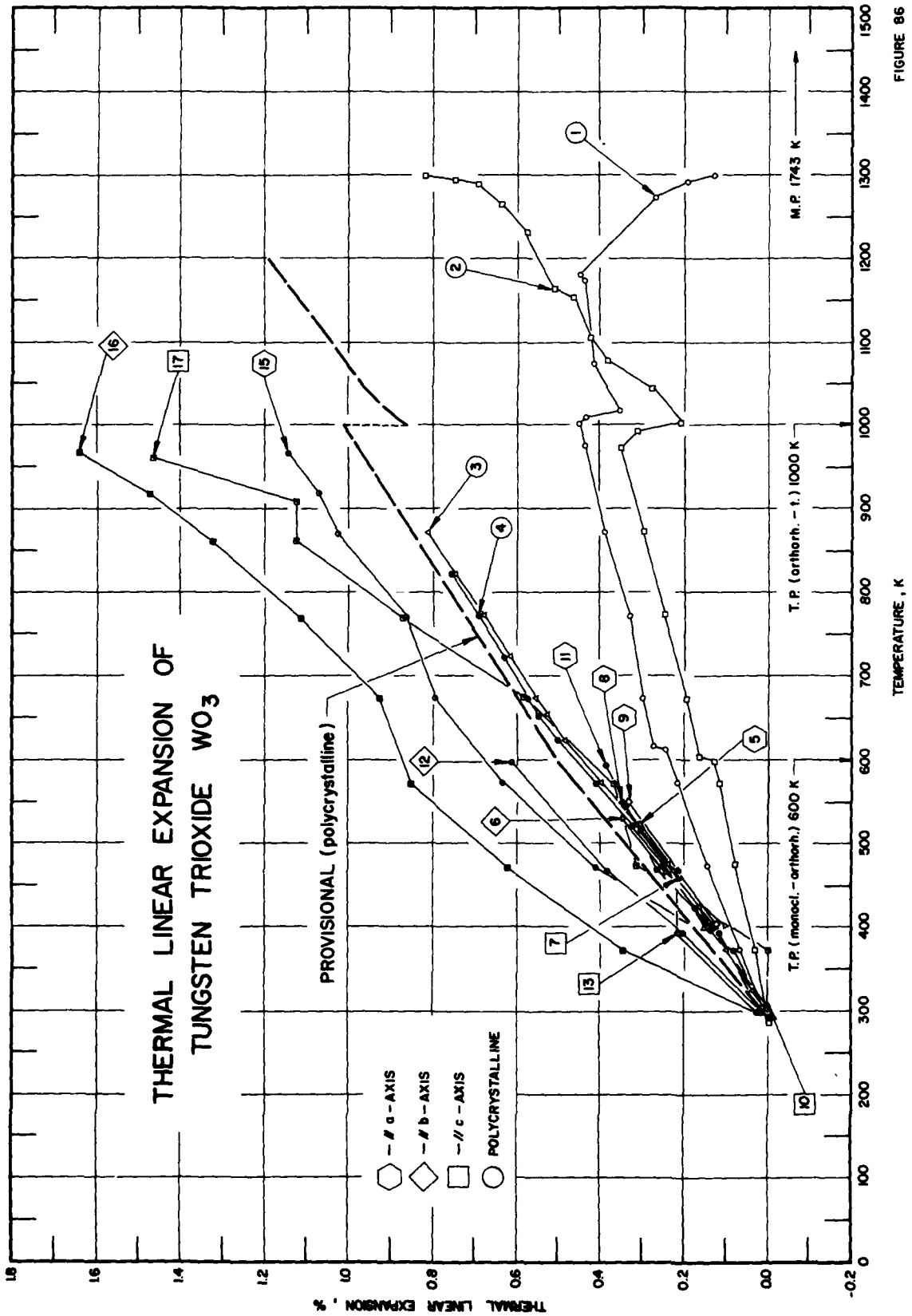

THERMAL LINEAR EXPANSION OF TUNGSTEN TRIOXIDE WO_3
PROVISIONAL (polycrystalline)
// a - AXIS
// b - AXIS
// c - AXIS
POLYCRYSTALLINE
M.P. 1743 K
T.P. (orthorh. - t.) 1000 K
T.P. (monocl. - orthorh.) 600 K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K

FIGURE 86

SPECIFICATION TABLE 86. THERMAL LINEAR EXPANSION OF TUNGSTEN TRIOXIDE WO_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	189	Polaczkowa, E. and Stoch, L.	1968	L	305-1300		Rod specimen 10 mm long; prepared by pressing with oleic acid under 7500 atm; oleic acid does not react with WO_3 and evaporates below 573 K; expansion measured with heating rate 10 degree per min; monoclinic phase between 293 and 603 K, orthorhombic phase 603 to 1008 K, tetragonal phase 1008 to 1183 K.
2	189	Polaczkowa, E. and Stoch, L.	1968	L	1300-286		The above specimen; expansion measured with decreasing temperature; zero-point correction of 0.693% determined by graphical interpolation.
3	188	Takamori, T.	1964	L	303-873	Sample A	95^+ pure; polycrystalline specimen; 3-4 mm dia, 50 mm long; prepared by mixing reagent grade WO_3 obtained from Woko Pure Chemical Industries and water; dry-pressed at 2500 kg cm^{-2}, sintered at 1173 K; heating rate 2.5-3 C per min; expansion measured in air atm; zero-point correction of 0.0129% determined by graphical extrapolation.
4	188	Takamori, T.	1964	L	303-873	Sample B	Similar to the above specimen; except sintered at 1373 K; zero-point correction of 0.0129% determined by graphical extrapolation.
5	191	Rosen, C., Banks, E. and Post, B.	1956	X	304-881		Powdered specimen; obtained from A.D. Mackay Inc; monoclinic unit cell transformed to orthorhombic form near 603 K; expansion measured along a-axis; length of cell edge of monoclinic phase reported at 304 K is 7.2923 Å; 7.2909 Å at 293 K determined by graphical extrapolation; average coefficient of expansion in range 293-573 K is 13×10^{-6} C^{-1} and 573-973 K - 17×10^{-6} C^{-1}.
6	191	Rosen, C., et al.	1956	X	302-885		The above specimen; expansion measured along b-axis; length of cell edge of monoclinic phase reported at 302 K is 7.5180 Å; 7.5172 Å at 293 K determined by graphical extrapolation; average coefficient of expansion in range 293-573 K is 14×10^{-6} C^{-1} and 573-973 K - 1.3×10^{-6} C^{-1}.
7	191	Rosen, C., et al.	1956	X	398-876		The above specimen; expansion measured along c-axis; length of cell edge of monoclinic phase reported at 398 K is 3.8367 Å; 3.8320 Å at 293 K determined by graphical extrapolation; average coefficient of expansion in range 293-573 K is 14×10^{-6} C^{-1} and 573-973 K - 18×10^{-6} C^{-1}.
8	191	Rosen, C., et al.	1956	X	304-969		Specimen obtained from Fisher Scientific Co; expansion measured along a-axis; author concludes at 573 K structure changes from monoclinic to orthorhombic symmetry; transition extends over about 100 C; length of cell edge reported at 304 K is 7.2923 Å; 7.2909 Å at 293 K determined by graphical extrapolation.
9	191	Rosen, C., et al.	1956	X	302-980		The above specimen; expansion measured along b-axis; length of cell edge reported at 302 K is 7.5180 Å; 7.5172 Å at 293 K determined by graphical extrapolation.
10	191	Rosen, C., et al.	1956	X	305-968		The above specimen; expansion measured along c-axis; length of cell edge reported at 305 K is 3.8322 Å; 3.8320 Å at 293 K determined by graphical extrapolation.
11	192	Perri, J.A., Banks, E. and Post, B.	1957	X	297-973		Powdered specimen; obtained from Brooklyn Polytechnic Inst; phase transformation from monoclinic to orthorhombic at about 593 K and from orthorhombic to tetragonal at 993 K; (200) reflection of monoclinic and orthorhombic phases along a-axis determined; lattice parameter reported at 297 K is 3.6453 Å; 3.6446 Å at 293 K is 3.7600 Å.
12	192	Perri, J.A., et al.	1957	X	391-986		The above specimen; (020) reflection of monoclinic and orthorhombic phases along b-axis determined; lattice parameter reported at 293 K is 3.7600 Å.

SPECIFICATION TABLE 86. THERMAL LINEAR EXPANSION OF TUNGSTEN TRIOXIDE WO_3 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
13	192	Perri, J. A., Banks, E. and Post, B.	1957	X	297-973		The above specimen; (001) reflection of monoclinic, orthorhombic and tetragonal phases along c-axis determined; lattice parameter reported at 297 K is 3.8407 Å; 3.8397 Å at 293 K determined by graphical extrapolation.
14*	192	Perri, J. A., et al.	1957	X	978-1196		The above specimen; except (110) reflection of tetragonal phase determined.
15	193	Ueda, R. and Ichinokawa, T.	1951	X	293-966		Phase transformation from orthorhombic to tetragonal phase observed between 973 and 1023 K; expansion measured along a-axis of orthorhombic and tetragonal phases; lattice constant reported at 293 K is 7.066 Å; no phase transition below 973 K concluded by authors.
16	193	Ueda, R. and Ichinokawa, T.	1951	X	293-967		The above specimen; expansion measured along b-axis of orthorhombic and tetragonal phases; lattice constant reported at 293 K is 7.244 Å.
17	193	Ueda, R. and Ichinokawa, T.	1951	X	293-959		The above specimen; expansion measured along c-axis of orthorhombic and tetragonal phases; lattice constant reported at 293 K is 3.808 Å.
18*	339	Sawada, S., Ando, R. and Nomura, S.	1951	L	307-1143		Crystal structure changes from orthorhombic to tetragonal (a=b) at 973-1023 K; expansion measured at heating rate 2 C per min; a rather gradual expansion observed at 603 K and a remarkable contraction at 1028 K; only data on coefficient of thermal linear expansion from smoothed curve reported.
19*	340	Sawada, S.	1956	X	1114-1473		Lattice constants near 1183 K obtained by analyses of (122), (131) lines; no change of crystal symmetry at this transition, a slight anomaly of lattice constants; lattice constant of a-axis measured; reported at 1114 K is 5.229 Å; this curve is here reported using the first given temperature (1114 K) as reference temperature at which $\Delta L/L = 0$.
20*	340	Sawada, S.	1956	X	1114-1434		The above specimen; lattice constant of c-axis measured; reported at 1114 K is 3.888 Å; this curve is here reported using the first given temperature (1114 K) as reference temperature at which $\Delta L/L = 0$.
21*	340	Sawada, S.	1956	X	1386-1547		Similar to the above specimen; lattice constants near 1503 K obtained by analysis of (122), (131) lines; no change of crystal symmetry; lattice constant of a-axis measured; reported at 1386 K is 5.233 Å; this curve is here reported using the first given temperature (1386 K) as reference temperature at which $\Delta L/L = 0$.
22*	340	Sawada, S.	1956	X	1386-1547		The above specimen; lattice constant of c-axis measured; reported at 1386 K is 3.898 Å; this curve is here reported using the first given temperature (1386 K) as reference temperature at which $\Delta L/L = 0$.
23*	341	Sawada, S.	1956	O	1079-1254		99.9 pure, greenish yellow powder; prepared by pressing powder into disk and sintering at 1373 K for 2 hrs; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
24*	341	Sawada, S.	1956	O	1426-1562		Similar to the above specimen; expansion measured with increasing temperature; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
25*	187	Takamori, T. and Tomozawa, M.	1965	L	302-796	$W_{18}O_{49}$	Rod specimen; 15 mm dia, 30 mm long; degreased in trichloroethylene, heated in hydrogen at 1372 K for 15 min, electrolytically polished; preoxidized, sheathed with glass; fused to metal to make sealed specimen; zero-point correction of -0.150% determined by graphical extrapolation.

* Not shown in figure.

SPECIFICATION TABLE 86. THERMAL LINEAR EXPANSION OF TUNGSTEN TRIOXIDE WO_3 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
26*	188	Takamori, T.	1964	L	303-773	$W_{18}O_{49}$	95+ pure; polycrystalline specimen; 5 x 5 mm cross section, 55 mm long; prepared by stoichiometrically mixing WO_3 of Wako Pure Chemical Ind. and metallic W of Tokyo Tungsten Co. in ratio $WO_{2.72}$; heated to 1273 K for 40 hrs in nitrogen atm, crushed, dry-pressed, sintered 15 min; heating rate 2.5-3 C per min; expansion measured in air atm; zero-point correction of 0.0010% determined by graphical extrapolation.
27*	188	Takamori, T.	1964	L	303-773	$W_{20}O_{58}$	Similar to the above specimen except mixing WO_3 and W in ratio $WO_{2.90}$; and heated to 1323 K for 80 hrs; zero-point correction of 0.0001% determined by graphical extrapolation.

* Not shown in figure.

DATA TABLE 86. THERMAL LINEAR EXPANSION OF TUNGSTEN TRIOXIDE WO_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
305	0.019
373	0.067
473	0.142
573	0.217
611	0.244
616	0.276
673	0.297
773	0.348
873	0.392
974	0.435
1002	0.447
1010	0.432
1018	0.348
1073	0.415
1173	0.435
1180	0.445
1273	0.267
1292	0.193
1300	0.127

CURVE 2

T	$\Delta L/L_0$
1300	0.820
1294	0.744
1289	0.693
1266	0.637
1231	0.572
1164	0.509
1155	0.463
1106	0.422
1077	0.382
1044	0.278
1001	0.209
991	0.313
973	0.347
874	0.298
773	0.248
673	0.197
603	0.165
597	0.129
573	0.117
475	0.081
373	0.034
286	-0.003

CURVE 3

T	$\Delta L/L_0$
303	0.0129
323	0.0387
373	0.1022
423	0.1657
473	0.2396
523	0.3128
573	0.3963
623	0.4835
653	0.5262
673	0.5517
723	0.6175
773	0.6807
823	0.7479
873	0.8137

CURVE 4

T	$\Delta L/L_0$
303	0.0129*
323	0.0387*
373	0.1046*
423	0.1714
473	0.2423
523	0.3191
573	0.4086
623	0.5035
653	0.5445
673	0.5693
723	0.6305
773	0.6907
823	0.7512
873	0.8161*

CURVE 5

T	$\Delta L/L_0$
304	0.019* monocl.
397	0.154
468	0.229
523	0.311
T	a(Å)
672	7.3235* orthorh.
775	7.3361*
881	7.3534*

CURVE 6

T	$\Delta L/L_0$
302	0.011* monocl.
402	0.101
466	0.242
531	0.341
T	b(Å)
686	7.5438* orthorh.
782	7.5450*
885	7.5440*

CURVE 7

T	$\Delta L/L_0$
398	0.123 monocl.
457	0.214
519	0.305
T	c(Å)
665	3.8511* orthorh.
770	3.8599*
876	3.8691*

CURVE 8

T	$\Delta L/L_0$
304	0.019* monocl.
402	0.134
549	0.347
T	a(Å)
663	7.3298* orthorh.
969	7.3664*

CURVE 9

T	$\Delta L/L_0$
302	0.011* monocl.
403	0.130
550	0.334
T	b(Å)
663	7.5459* orthorh.
980	7.5436*

CURVE 10

T	$\Delta L/L_0$
305	0.005 monocl.
396	0.136
544	0.339
T	c(Å)
672	3.8545* orthorh.
968	3.8749*

CURVE 11

T	$\Delta L/L_0$
297	0.019 monocl.
391	0.118
468	0.266
595	0.384
T	d(Å) // to a-axis
595	3.6586* orthorh.
682	3.6681*
775	3.6753*
842	3.6787*
903	3.6855*
921	3.6866*
947	3.6891*
973	3.6911*

CURVE 12

T	$\Delta L/L_0$
293	0.000 monocl.
391	0.205
467	0.383
597	0.612
T	d(Å) // to b-axis
597	3.7830* orthorh.
682	3.7798*
782	3.7791*
843	3.7778*
903	3.7767*
924	3.7778*
946	3.7717*
972	3.7764*
981	3.7711*
986	3.7753*

CURVE 13

T	$\Delta L/L_0$
297	0.026 monocl.
391	0.219
467	0.219
T	d(Å) // to c-axis
601	3.8672* orthorh.
687	3.8650*
785	3.8762*
852	3.8796*
910	3.8812*
932	3.8868*
950	3.8847*
972	3.8936*
973	3.8897*
988	3.8970* t.
1012	3.9072*
1025	3.9093*
1081	3.9132*
1094	3.9132*
1104	3.9136*
1124	3.9150*
1148	3.9160*
1172	3.9143*

CURVE 14*

T	d(Å) // to (110)
978	3.7184 t.
980	3.7246
1000	3.7197
1024	3.7197
1072	3.7242
1092	3.7275
1117	3.7249
1152	3.7284
1196	3.7320

CURVE 15

T	$\Delta L/L_0$
293	0.000* orthorh.
372	0.085
470	0.410
573	0.637

CURVE 15 (cont.)

T	$\Delta L/L_0$
673	0.792
772	0.863
871	1.033
919	1.075
966	1.146
T	a(Å)
1022	7.239* t.
1072	7.256*
1139	7.266*
1220	7.286*
1310	7.301*
1403	7.319*

CURVE 16

T	$\Delta L/L_0$
293	0.000* orthorh.
372	0.345
470	0.621
573	0.856
673	0.925
770	1.118
863	1.325
917	1.477
967	1.643
T	b(Å)
1022	7.239* t.
1072	7.256*
1139	7.266*
1220	7.286*
1310	7.301*
1403	7.319*

CURVE 17

T	$\Delta L/L_0$
293	0.000* orthorh.
373	0.000
473	0.315
572	0.368
674	0.578
770	0.866

* Not shown in figure.

DATA TABLE 86. THERMAL LINEAR EXPANSION OF TUNGSTEN TRIOXIDE WO_3 (continued)

T	$\Delta L/L_0$
CURVE 17 (cont.)	
864	1.129
909	1.129
959	1.470
T	c(Å)
1015	3.892* t.
1062	3.900*
1131	3.904*
1209	3.913*
1315	3.923*
1420	3.932*
CURVE 19*, †	
T	$\Delta L/L_0$
1114	0.000
1133	0.021
1152	0.103
1172	-0.084
1193	-0.222
1214	-0.021
1234	0.115
1253	0.019
1263	-0.023
1302	0.117
1345	0.078
1404	0.078
1434	0.191
1473	0.151
CURVE 20*, †	
1114	0.000
1133	0.015
1154	0.087
1173	-0.095
1194	0.013
1213	0.183
1234	0.077
1250	0.010
1262	0.185
1302	0.111
1342	0.216
1403	0.216
1434	0.175

T	$\Delta L/L_0$
CURVE 21*, †	
1386	0.000
1426	0.073
1453	0.073
1489	0.182
1494	0.246
1506	0.246
1516	0.246
1518	0.357
1547	0.489
CURVE 22*, †	
1386	0.000
1426	0.056
1453	0.056
1489	0.233
1494	0.223
1506	0.223
1516	0.233
1519	0.341
1547	0.398
CURVE 23*, †	
1079	0.00
1085	5.75
1091	8.25
1097	9.50
1103	10.50
1109	10.25
1116	10.25
1121	10.25
1128	12.75
1133	13.50
1139	15.00
1146	16.00
1152	17.00
1157	17.75
1163	17.75
1170	19.50
1176	20.50
1182	21.25
1188	22.75
1194	24.50
1200	29.00
1206	41.75
1213	36.00
1219	28.50

T	$\Delta L/L_0$
CURVE 23 (cont.) *, †	
1224	21.00
1230	10.25
1236	0.00
1243	-14.50
1248	-28.00
1254	-49.75
CURVE 24*, †	
1426	0.00
1432	0.00
1439	0.00
1446	0.22
1452	0.22
1459	0.22
1466	0.31
1473	0.31
1480	0.31
1486	0.31
1494	0.17
1499	-0.31
1507	-0.44
1514	-0.78
1521	-1.18
1528	-1.83
1535	-2.57
1541	-3.14
1548	-4.19
1555	-5.54
1562	-6.98
CURVE 25*	
302	0.001
433	0.014
558	0.033
639	0.048
766	0.078
796	0.080
CURVE 26*	
303	0.0010
323	0.0031
373	0.0068
423	0.0111
473	0.0161
523	0.0230

T	$\Delta L/L_0$
CURVE 26 (cont.) *	
573	0.0307
623	0.0394
673	0.0504
723	0.0627
753	0.0693
773	0.0731
CURVE 27*	
303	0.0001
323	0.0013
373	0.0032
423	0.0033
473	0.0032
523	0.0036
573	0.0049
623	0.0064
673	0.0032
723	-0.0040
753	-0.0063
773	-0.0071

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

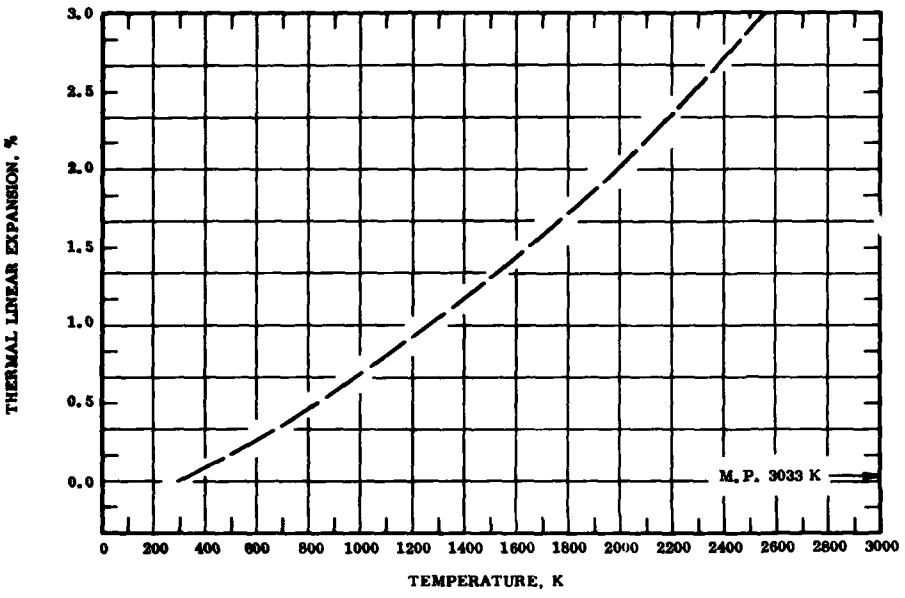
DATA TABLE 86. COEFFICIENT OF THERMAL LINEAR EXPANSION OF TUNGSTEN TRIOXIDE WO_3

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 18*	
307	10.0
323	10.2
348	11.2
373	11.2
398	11.5
423	12.0
448	12.9
473	13.6
498	14.5
523	15.3
548	16.2
573	17.8
598	20.4
623	16.2
648	10.9
673	9.5
698	8.8
723	8.4
748	8.1
773	8.1
798	8.4
823	9.0
848	9.9
873	10.4
898	11.1
923	12.0
948	12.9
973	13.2
998	12.9
1023	2.2
1026	0.0
1026	-161.0
1028	-19.9
1036	0.0
1048	29.0
1067	32.8
1073	31.1
1073	19.4
1098	8.2
1123	4.7
1143	3.4

* No figure given.

FIGURE AND TABLE NO. 87R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF URANIUM DIOXIDE UO_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	9.4
400	0.102	9.6
600	0.275	9.9
800	0.490	10.3
1000	0.709	10.9
1200	0.930	11.6
1400	1.175	12.5
1600	1.440	13.4
1800	1.715	14.6
2000	2.017	15.8
2200	2.340	17.2
2400	2.705	18.7
2600	3.100	20.4

REMARKS

The provisional values are based on the data for the stoichiometric, pure samples, (curves 1, 12, 14, 27 and 32). The experimental data reported in curves 17 to 26 are largely scattered. This may be due to the samples' variation in density and grain size. These values are considered accurate to within ±7% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.274 + 9.327 \times 10^{-4}\, T - 4.960 \times 10^{-9}\, T^2 + 5.566 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

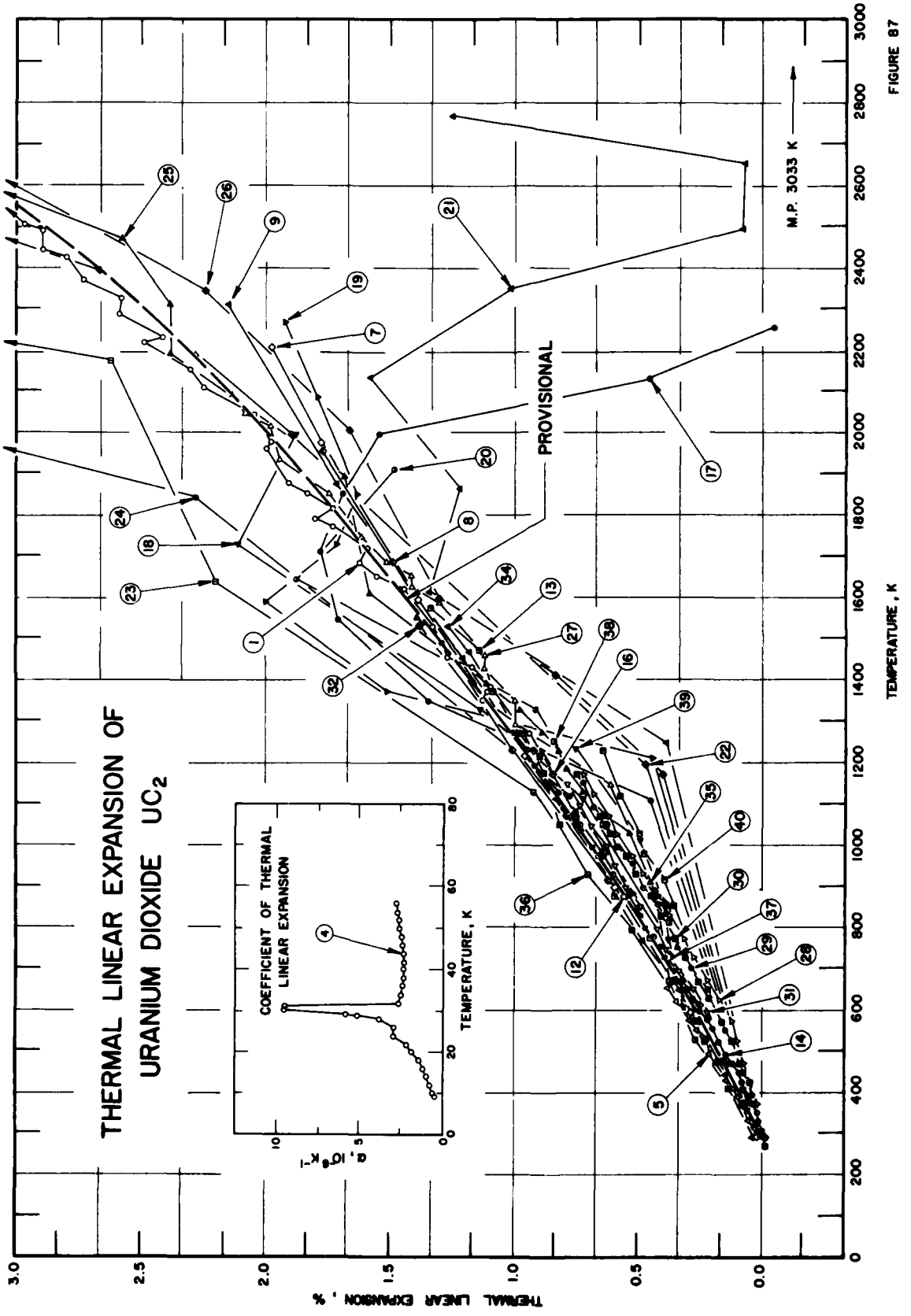

THERMAL LINEAR EXPANSION OF
URANIUM DIOXIDE UC2
PROVISIONAL
M.P. 3033 K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
α, 10⁻⁶ K⁻¹
TEMPERATURE, K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K

FIGURE 87

SPECIFICATION TABLE 87. THERMAL LINEAR EXPANSION OF URANIUM DIOXIDE UO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	210, 221	Conway, J.B., Fincel, R.M., Jr., and Hein, R.A.	1963	T	315-2535		99.9 pure; rod specimen 0.25 x 2.0 in.; powder pressed at 30 000 psi; sintered at 2473 K for 21 hr; centerless ground to size in hydrogen atmosphere; 95.5% theoretical density; zero-point correction of 0.02% determined by graphical extrapolation.
2*	211	Porneuf, A.	1962		573-1073		Extruded rod specimen; obtained from Compagnie Industrielle Des Combustibles Atomiques Frittes, France; coefficient of thermal linear expansion reported by author and integrated by TPRC.
3*	211	Porneuf, A.	1962		300-1073		Sintered pellet having the same density as the above specimen.
4*	212	Brandt, O.G. and Walker, C.T.	1967	L	9-56		Single crystal specimen; normalized length change for [100] direction measured; first-order transition at Néel temperature (30.8 K), abrupt change in length of the order of 20 ppm; data from smoothed curve without specified reference temperature; coefficient of thermal linear expansion also reported.
5	213	McCreight, L.R.	1952	I	293-656		Specimen sintered in hydrogen atmosphere at 2223 K to 85% theoretical density; expansion measured in argon atmosphere.
6*	214	de Kouchkovsky, R. and Lecomte, M.	1968	X	20-44		Expansion of lattice parameter measured with $CuK\alpha_1$ radiation; abrupt change in length at 31.5 K; only data on lattice parameter reported.
7	215	Baldock, P.J., Spindler, W.E., and Baker, T.W.	1965	X	297-2203	Specimen 1 O/U = 1.991	AGR UO_2 powder of O:U ratio 1.991 ± 0.005:1, 0.03 Fe, 0.02 Al, 0.0043 C, 0.0020 N_2, 0.0015 Ni, 0.0015 Mg, 0.0006 H_2, 0.0002 Pb; specimen 0.125 x 0.125 x 0.25 in., surface area 4 $m^2 g^{-1}$; prepared by calcination and reduction of ammonium diurinate; pressed, sintered at 1923 K in hydrogen atmosphere; re-reduced at 1473 K, then kept under vacuum; expansion measured in first cycle; lattice parameter reported at 297.2 K is 5.4722 ± 0.0003 Å; 5.4715 Å at 293.2 K determined by graphical extrapolation.
8	215	Baldock, P.J., et al.	1965	X	1953-296	Specimen 1 O/U = 1.991	The above specimen; expansion measured on first cycle with decreasing temperature; lattice parameter reported at 296.2 K is 5.4704 ± 0.0004 Å; 5.4700 Å at 293.2 K determined by graphical extrapolation.
9	215	Baldock, P.J., et al.	1965	X	295-2313	Specimen 2 O/U = 1.984	Similar to the above specimen except O:U ratio 1.984 ± 0.007:1; heated in hydrogen atmosphere at 2073 K for 2 hr prior to measurement; lattice parameter reported at 295.2 K is 5.4732 ± 0.0003 Å; 5.4710 Å at 293.2 K determined by graphical extrapolation.
10*	216	Battelle Institute	1962	L	293-1373		Rod specimen, about 50 mm long; expansion measured in hydrogen atmosphere.
11*	216	Battelle Institute	1962		293-1373		98.58 UO_2, 1.42 BeO (calculated composition based on theoretical density and zero porosity on UO_2 + 5 vol% BeO).
12	150	Vaughan, D.A. and Schwartz, C.M.	1962	X	296-1073	O/U = 2.01	Specimen 0.1 mm diameter, 1-2 mm long; protected from oxidation by encapsulation in evacuated and sealed vitreous silica tubes; lattice parameter reported at 296 K is 5.4704 Å; 5.4700 Å at 293 K determined by graphical extrapolation.
13	72	Fulkerson, S.D.	1959	L	273-1573		Rod specimen, 0.25 in. diameter, 1 in. long; isostatically pressed and sintered to 2023 K; 95% theoretical density; expansion measured in argon atmosphere; zero-point correction of -1.316% determined by graphical interpolation.
14	45	Brett, N.H. and Russell, L.E.	1960	L	298-1273	O/U = 2.01	Specimen of O/U ratio 2.01, 12.3 mm long; cut from large pellet made by compacting non-stoichiometric UO_2 powder with binder, heating in argon to 1723 K and cooling in hydrogen; bulk density 10.20 g cm^{-3}; averaged values of four measurements; zero-point correction of 0.0005% determined by graphical extrapolation.

* Not shown in figure.

SPECIFICATION TABLE 87. THERMAL LINEAR EXPANSION OF URANIUM DIOXIDE UO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
15*	45	Brett, N.H. and Russell, L. E.	1960	L	298-1273		1.01 PuO_2 added; O/U ratio 2.00 assuming Pu remained as PuO_2; specimen 16.5 mm long; plutonium hydroxide and ammonium diuranate coprecipitated and converted to oxide powder; compacted with binder and fired in hydrogen atmosphere at 1823 K for 3 hr; bulk density 10.51 g cm^{-3}; averaged values of four measurements; zero-point correction of 0.0010% determined by graphical extrapolation.
16	217	Lambertson, W.A. and Handwerk, J.H.	1956	I	291-1223		Specimen sintered; absolute density 10.25 g cm^{-3}; m.p. 3153 K.
17	218	Halden, F.A., Wohlers, H.C., and Reinhart, R. H.	1959	T	303-2255		0.01 Si, 0.0015 Al, 0.0002 Cu; cylindrical specimen 0.480 in. diameter, 0.250 to 1 in. long; obtained from the Nuclear Materials Corp. of Appollo, Pennsylvania; prepared by normal cold pressing and sintering technique; density 8.45 g cm^{-3}; normal grain.
18	218	Halden, F.A., et al.	1959	T	1996-298		The above specimen; expansion measured with decreasing temperature; zero-point correction of 3.27% determined by graphical extrapolation.
19	218	Halden, F.A., et al.	1959	T	303-2268		Similar to the above specimen; density 10.19 g cm^{-3}; large grain; expansion measured with increasing temperature.
20	218	Halden, F.A., et al.	1959	T	1901-303		The above specimen; expansion measured with decreasing temperature.
21	218	Halden, F.A., et al.	1959	T	283-2761		Similar to the above specimen; initial density 9.33 g cm^{-3}; expansion measured with increasing temperature on second test; zero-point correction of -0.02% determined by graphical interpolation.
22	218	Halden, F.A., et al.	1959	T	2498-294		The above specimen; expansion measured with decreasing temperature on second test; zero-point correction of 3.13% determined by graphical extrapolation.
23	218	Halden, F.A., et al.	1959	T	300-3125		The above (curve no. 20) specimen; expansion measured with increasing temperature on second test; zero-point correction of ± 0.00% determined by graphical extrapolation.
24	218	Halden, F.A., et al.	1959	T	3125-300		The above specimen; expansion measured with decreasing temperature on second test; zero-point correction of ± 0.00% determined by graphical extrapolation.
25	218	Halden, F.A., et al.	1959	T	298-3125		Similar to the above specimen; large grain size; expansion measured with increasing temperature on second test; zero-point correction of ± 0.00% determined by graphical extrapolation.
26	218	Halden, F.A., et al.	1959	T	2729-296		The above specimen; expansion measured with decreasing temperature on second test; zero-point correction of 0.18% determined by graphical extrapolation.
27	176	Hoch, M. and Momin, A.C.,	1969	X	298-2226		99.9 pure powder; cylindrical rod specimen; 0.160 in. diameter, 0.480 in. long; average particle size 100-150 mesh; obtained from K & K Laboratories, Plainview, N. Y.; pressed without any binder; lattice parameter expansion measured; zero-point correction of ± 0.00% determined by graphical extrapolation.
28	219	Murray, P. and Thackray, R.W.	1957	L	298-1173		Sintered specimen; density 7.2 g cm^{-3}; purified argon atmosphere around specimen to prevent formation of higher oxides with attendant high volume expansion; heating rate 10 C per min; expansion measured in argon atmosphere.

* Not shown in figure.

SPECIFICATION TABLE 87. THERMAL LINEAR EXPANSION OF URANIUM DIOXIDE UO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
29	219	Murray, P. and Thackray, R.W.	1957	L	349-1150		Similar to the above specimen; heating rate 3.5 C per min.
30	219	Murray, P. and Thackray, R.W.	1957	L	325-1173		Similar to the above specimen; density 8.54 g cm^{-3}; heating rate 3.5 C per min.
31	219	Murray, P. and Thackray, R.W.	1957	L	401-1150		Similar to the above specimen; density 10.1 g cm^{-3}; heat rate 10 C per min.
32	220	Burdick, M.D. and Parker, H.S.	1956	L	300-1533		0.001-0.01 Al and Fe, 0.0001-0.001 Ca and Mg, <0.0001 Cu; specimen 0.125 x 0.25 x 1.5 in.; obtained from Norton Co.; prepared by hydrostatic pressing, firing and lapping; arc-fused; particle fraction 0 to 5 μ.
33*	220	Burdick, M.D. and Parker, H.S.	1956	L	300-1533		Similar to the above specimen; particle fraction 15 to 20 μ.
34	142	Roth, J. and Halteman, E.K.	1965	X	328-1530	O/U = 2.08	ThO_2 added as internal standard for temperature determination; oxygen-to-metal ratio 2.08:1; lattice parameter reported at 328.2 K is 5.4686 Å; 5.4675 Å at 293.2 K determined by graphical extrapolation.
35	223	Ferguson, I.F. and Street, R.S.	1963	X	283-1549		Platinum mixed with specimen as internal temperature standard; two face-centered cubic phases of UO_{2+x} and U_4O_{9-y} in equilibrium at various temperatures; cube cell edge expansion measured with Ni-filtered CuKα radiation; 5.4680 Å at 293.2 K.
36	222	Gronvold, F.	1955	X	293-1219		Specimen prepared by heating pure U_3O_8 in dried hydrogen gas in alumina boat, cooled in hydrogen atmosphere or vacuum; lattice constant reported at 293.2 K is 5.4704 Å.
37	222	Gronvold, F.	1955	X	729-1224	O/U = 2.05	Specimen prepared by mixing UO_3 and U_3O_8 to constant weight at 1073 K; consist of two phases of UO_2 and U_4O_9 below 773 K and one UO_2 phase above 773 K; lattice constant expansion calculated by assuming 5.4704 Å at 293.2 K.
38	222	Gronvold, F.	1955	X	293-1242	O/U = 2.10	Similar to the above specimen; consist of two phases of UO_2 and U_4O_9 up to 823 K and homogeneous above; lattice constant reported at 293.2 K is 5.4696 Å.
39	222	Gronvold, F.	1955	X	293-1232	O/U = 2.15	Similar to the above specimen; consist of two phases of UO_2 and U_4O_9 between 293 and 853 K; lattice constant reported at 293.2 K is 5.4698 Å.
40	222	Gronvold, F.	1955	X	293-1232	O/U = 2.20	Similar to the above specimen; consist of two phases of UO_2 and U_4O_9 between 293 and 1233 K; lattice constant reported at 293.2 K is 5.4708 Å.
41*	338	Leblanc, J.M. and Andriessen, H.	1962	L	293-1273		Pellet specimen; prepared by sintering powder; averaged values of 3 runs.
42*	338	Leblanc, J.M. and Andriessen, H.	1962	L	293-1273	O/U = 2.10	Similar to the above specimen.
43*	338	Leblanc, J.M. and Andriessen, H.	1962	L	293-1273	O/U = 2.21	Similar to the above specimen.

* Not shown in figure.

DATA TABLE 87. THERMAL LINEAR EXPANSION OF URANIUM DIOXIDE UO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
315	0.02
1263	0.94
1349	1.14
1366	1.12
1380	1.10
1433	1.15*
1433	1.17
1449	1.25*
1454	1.27
1490	1.29
1533	1.34
1537	1.32*
1548	1.39*
1620	1.45
1655	1.56
1685	1.62
1720	1.58
1770	1.73
1788	1.81
1817	1.74
1849	1.84*
1849	1.86
1879	1.91
1906	1.90*
1960	2.00
1975	1.97
1981	2.05*
2043	2.05
2047	2.09*
2048	2.15*
2108	2.25
2154	2.30
2154	2.36*
2220	2.49
2234	2.42
2244	2.46*
2282	2.59
2307	2.56
2316	2.58*
2327	2.58
2327	2.62*
2369	2.77
2385	2.74*
2427	2.81
2442	2.90
2491	2.90

CURVE 1 (cont.)

T	$\Delta L/L_0$
2512	2.97
2519	3.04*
2535	3.08

CURVE 2*, ‡

T	$\Delta L/L_0$
573	0.262
873	0.543
1073	0.744

CURVE 3*

T	$\Delta L/L_0$
300	0.006
673	0.346
1073	0.842

CURVE 4*

T	$\Delta L/L_0$
9.4	0.103×10^{-2}
10.0	0.112
12.0	0.130
14.0	0.149
16.0	0.173
18.0	0.202
20.0	0.234
22.0	0.275
24.0	0.331
26.0	0.409
28.0	0.498
28.7	0.545
29.1	0.575
30.0	0.664
30.6	0.873
31.3	0.898
32.0	0.919
34.0	0.977
36.0	1.025
38.0	1.075
40.0	1.124
42.0	1.177
44.0	1.225
46.0	1.281
48.0	1.326
50.0	1.368
52.0	1.418
54.0	1.469
56.0	1.516

CURVE 5

T	$\Delta L/L_0$
293	0.000
310	0.025
335	0.049
363	0.077
389	0.100
412	0.127
431	0.151
472	0.198
496	0.211
528	0.247
553	0.260
574	0.294
620	0.342
656	0.387

CURVE 6*

T	a(Å)
20.0	5.46162
24.0	5.46163
27.0	5.46168
28.5	5.46172
28.8	5.46169
29.4	5.46174
29.5	5.46178
30.0	5.46175
30.5	5.46177
30.8	5.46177
31.3	5.46182
31.7	5.46195
32.2	5.46191
32.6	5.46189
33.3	5.46192
35.1	5.46196
37.2	5.46194
38.8	5.46197
43.9	5.46204

CURVE 7

T	$\Delta L/L_0$
297	0.0128
595	0.2851
894	0.5903
1218	0.9650
1598	1.3835
1973	1.7929
2203	1.9793

CURVE 8

T	$\Delta L/L_0$
1953	1.7733
1684	1.4991
1223	1.0109
916	0.6143
618	0.2578
296	0.0073*

CURVE 9

T	$\Delta L/L_0$
295	0.0402
296	0.0201*
533	0.2321*
648	0.3528
763	0.4844
918	0.6452*
1118	0.8499
1453	1.2100
1871	1.7163
2313	2.1769

CURVE 10*

T	$\Delta L/L_0$
293	0.000
473	0.164
673	0.363
873	0.570
1073	0.783
1273	1.006
1373	1.119

CURVE 11*

T	$\Delta L/L_0$
293	0.000
473	0.163
673	0.361
873	0.566
1073	0.791
1273	1.018
1373	1.124

CURVE 12

T	$\Delta L/L_0$
296	0.007*
473	0.177
668	0.355
869	0.556
1073	0.782

CURVE 13

T	$\Delta L/L_0$
273	-0.016
373	0.065
473	0.162
573	0.261
673	0.359*
773	0.458
873	0.559
973	0.660
1073	0.762*
1173	0.868
1273	0.973
1373	1.092
1473	1.214
1573	1.345

CURVE 14

T	$\Delta L/L_0$
298	0.0005*
323	0.0030
348	0.0095
373	0.0255
398	0.0455
423	0.0705
448	0.0930
473	0.1205
498	0.1480
523	0.1730
548	0.2005
573	0.2280
598	0.2555
623	0.2830
648	0.3080
673	0.3330*
698	0.3630
723	0.3855
748	0.4105
773	0.4355
798	0.4650
823	0.4880
848	0.5155*
873	0.5405
898	0.5705*
923	0.6005
948	0.6280*
973	0.6505*
998	0.6855

CURVE 14 (cont.)

T	$\Delta L/L_0$
1023	0.7105*
1048	0.7405
1073	0.7705*
1098	0.8005
1123	0.8305
1148	0.8605*
1173	0.8880*
1198	0.9180
1223	.9480
1248	0.9780*
1273	1.0105

CURVE 15*

T	$\Delta L/L_0$
298	0.0010
323	0.0085
348	0.0235
373	0.0435
398	0.0685
423	0.0910
448	0.1210
473	0.1410
498	0.1660
523	0.1935
548	0.2185
573	0.2435
598	0.2710
623	0.2935
648	0.3185
673	0.3510
698	0.3810
723	0.4060
748	0.4310
773	0.4585
798	0.4860
823	0.5160
848	0.5460
873	0.5735
898	0.5985
923	0.6235
948	0.6535
973	0.6860
998	0.7160
1023	0.7410
1048	0.7710
1073	0.7960

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 87. THERMAL LINEAR EXPANSION OF URANIUM DIOXIDE UO_2 (continued)

T	$\Delta L/L_0$
CURVE 15 (cont.)*	
1098	0.8260
1123	0.8560
1148	0.8910
1173	0.9135
1198	0.9385
1223	0.9660
1248	0.9960
1273	1.0260
CURVE 16	
291	-0.0014
373	0.0566
473	0.1556
573	0.2556
673	0.3536
773	0.4536*
873	0.5556*
973	0.6556
1073	0.7516
1173	0.8636
1223	0.9216
CURVE 17	
303	0.02*
1108	0.46
1341	1.33
1555	1.72
1716	1.77
1855	1.69
1991	1.54
2134	0.47
2255	-0.84
CURVE 18	
1996	1.88
1733	2.12
1324	1.15
1119	0.72
298	0.02*
CURVE 19	
303	0.02*
1209	0.44
1367	1.51
1586	2.00
1737	1.72
1859	1.64
2083	1.80
2268	1.93
CURVE 20	
1901	1.48
1644	1.88
1325	0.91
303	0.02*
CURVE 21	
288	-0.02*
1244	0.39
1616	1.35
1860	1.22
2137	1.57
2348	1.03
2498	0.08
2652	0.07
2761	1.25
CURVE 22	
2498	3.23
2384	2.66
1984	1.90
1191	0.46
294	0.00*
CURVE 23	
300	0.00
1139	0.92
1641	2.20
2177	2.63
2334	3.85
2569	4.02*
2726	5.22*
3125	7.29*
CURVE 24	
3125	7.29*
1840	2.28
1120	0.77
300	0.00*
CURVE 25	
298	0.00*
1234	0.82*
1604	1.57
1884	1.69
2195	2.39
2315	2.39
2473	2.57
2611	3.27*
3125	5.81*
CURVE 26	
2729	3.34*
2345	2.24
2004	1.67
1597	1.30
1407	0.83
1169	0.40
296	0.00*
CURVE 27	
298	0.00*
1144	0.61
1156	0.69*
1286	1.00
1343	1.00
1428	1.15
1460	1.15
1512	1.17*
1581	1.30
1622	1.41
1656	1.41
1682	1.51
1741	1.61
1854	1.75
1933	1.95
2017	1.98
2042	2.09
2055	2.11*
2084	2.15
2084	2.21*
2197	2.28
2226	2.42*
CURVE 28	
298	0.002*
373	0.025
472	0.073
524	0.100
573	0.132
621	0.175
674	0.223
722	0.271
773	0.321
822	0.373
873	0.419
922	0.472
973	0.521
1021	0.571
1073	0.621
1124	0.672
1173	0.720
CURVE 29	
349	0.023*
397	0.046
448	0.078
547	0.149
646	0.228
700	0.279
747	0.322*
797	0.371*
847	0.424
896	0.472
946	0.522
998	0.573
1049	0.624
1098	0.673
1150	0.722
CURVE 30	
325	0.013*
424	0.054
473	0.091
523	0.127
573	0.166
624	0.212
673	0.257
721	0.302
772	0.354
823	0.403
873	0.453
922	0.502
973	0.552
1022	0.603
1073	0.653
1123	0.704*
1173	0.754
CURVE 31	
401	0.080
499	0.153*
598	0.238
649	0.288
698	0.340
747	0.390
797	0.438
847	0.492
897	0.540
947	0.590
997	0.637
1048	0.690
1098	0.739
1150	0.789
CURVE 32	
300	0.0063*
673	0.34
1073	0.78
1533	1.37
CURVE 33*	
300	0.0063
673	0.34
1073	0.80
1533	1.40
CURVE 34	
328	0.0201*
337	0.0256*
405	0.1042*
443	0.1554
466	0.1774*
577	0.2761*
598	0.2944*
1080	0.7590
1273	0.9967
1364	1.1211*
1463	1.1888
1530	1.2601
CURVE 35	
283	-0.0091*
293	0.0000*
328	0.0109*
588	0.2834*
670	0.3566*
678	0.3273*
758	0.3566
845	0.3822
877	0.4279*
911	0.4645
920	0.4608*
945	0.4736*
1028	0.5449
1071	0.6035
1085	0.6510*
1137	0.7333
1146	0.7197*
1182	0.7790
1223	0.8229
1273	0.8851
1328	0.9875
1385	1.1228
1549	1.3899
CURVE 36	
293	0.0000*
523	0.2467
795	0.5191
934	0.7001
1051	0.8207
1219	0.9907
CURVE 37	
729	0.3710
793	0.4368*
880	0.5045
997	0.6361
1224	0.8957

* Not shown in figure.

DATA TABLE 87. THERMAL LINEAR EXPANSION OF URANIUM DIOXIDE UO_2 (continued)

T	$\Delta L/L_0$
CURVE 38	
293	0.0000*
411	0.1334
533	0.2651
670	0.3656
809	0.3656
872	0.4387
1058	0.6252
1242	0.8263
CURVE 39	
293	0.0000*
477	0.1992*
607	0.3071
771	0.3619
857	0.3875
CURVE 39 (cont.)	
1013	0.4972
1232	0.7513
CURVE 40	
293	0.0000*
325	0.0255*
359	0.0603
405	0.1169*
845	0.3564
916	0.3966
979	0.4734
1004	0.4843*
1028	0.4990
1120	0.5739
1228	0.6470
1233	0.6598*
CURVE 41*	
293	0.00
373	0.07
473	0.16
573	0.25
673	0.34
773	0.45
873	0.56
973	0.68
1073	0.80
1173	0.94
1273	1.06
CURVE 42*	
293	0.00
373	0.05
CURVE 42 (cont.)*	
473	0.13
573	0.21
673	0.32
773	0.45
873	0.60
973	0.73
1073	0.85
1173	0.95
1273	1.09
CURVE 43*	
293	0.00
373	0.05
473	0.13
573	0.23
CURVE 43 (cont.)*	
673	0.36
773	0.51
873	0.65
973	0.79
1073	0.90
1173	1.02
1273	1.12

DATA TABLE 87. COEFFICIENT OF THERMAL LINEAR EXPANSION OF URANIUM DIOXIDE UO_2

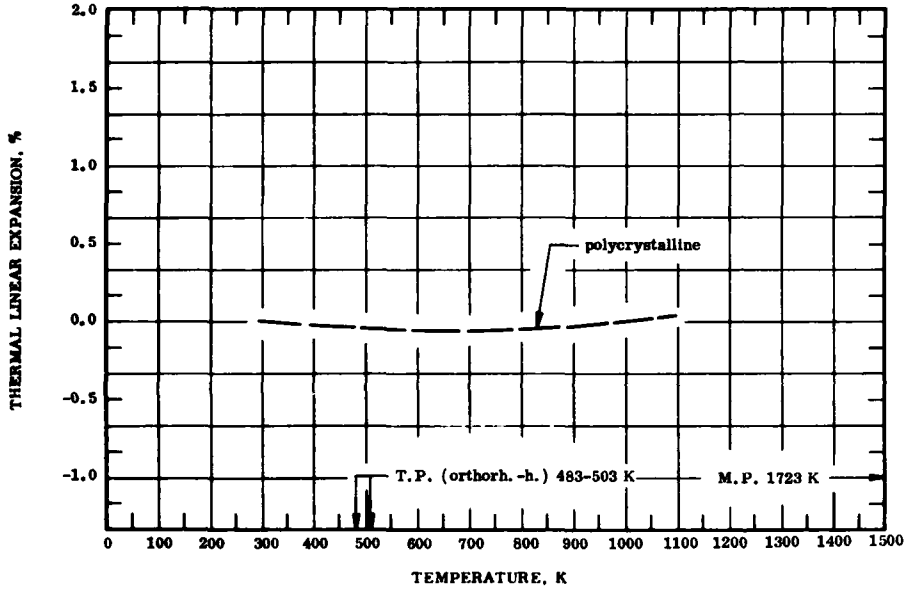
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 2*, ‡	
573	8.90
873	9.81
1073	10.30
CURVE 4	
9.4	0.46
10.0	0.53
12.0	0.74
14.0	0.95
16.0	1.20
18.0	1.46
20.0	1.81
22.0	2.17
24.0	2.81
CURVE 4 (cont.)	
26.0	2.81
28.0	3.72
28.7	5.04
29.1	5.86
30.6	9.50
31.3	9.50
32.0	2.66
34.0	2.50
36.0	2.41
38.0	2.37
40.0	2.37
42.0	2.36
44.0	2.36
46.0	2.41
48.0	2.45
CURVE 4 (cont.)*	
50.0	2.54
52.0	2.58
54.0	2.65
56.0	2.69

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 88R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF TRIURANIUM OCTAOXIDE U_3O_8



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	0.8
350	-0.003	-1.4
400	-0.013	-2.7
450	-0.027	-3.1
500	-0.043	-2.9
550	-0.056	-1.9
600	-0.060	-0.3
650	-0.061	0.2
700	-0.059	0.7
750	-0.054	1.3
800	-0.046	1.8
850	-0.036	2.3
900	-0.023	2.9
950	-0.007	3.4
1000	0.011	3.9
1050	0.031	4.4
1100	0.055	4.8

REMARKS

The provisional values for the stoichiometric, pure polycrystalline sample are based on the data reported in curves 15 to 18 and 22. The transition of the orthorhombic hexagonal structure occurs in the range 483 to 503 K (curve 19). These values are considered accurate to within ±10% and are represented approximately by the following equations:

$$\Delta L/L_0 = -0.356 + 2.768 \times 10^{-3}\, T - 6.733 \times 10^{-6}\, T^2 + 4.902 \times 10^{-9}\, T^3 \quad (293\text{-}600\ K)$$

$$\Delta L/L_0 = 0.177 - 7.736 \times 10^{-4}\, T + 6.619 \times 10^{-7}\, T^2 - 5.457 \times 10^{-11}\, T^3 \quad (600\text{-}1100\ K)$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±15%.

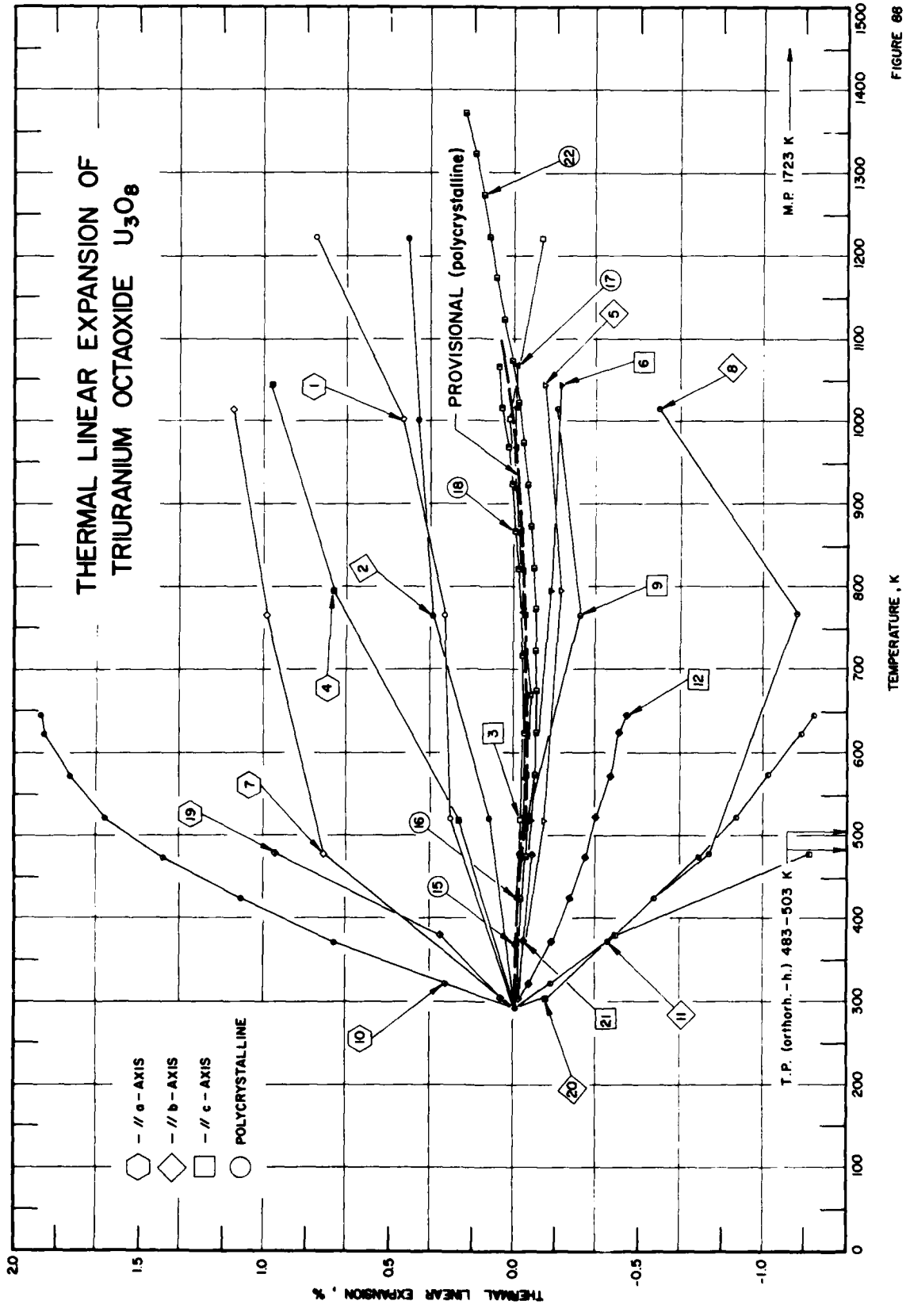

THERMAL LINEAR EXPANSION OF
TRIURANIUM OCTAOXIDE U_3O_8
PROVISIONAL (polycrystalline)
M.P. 1723 K
T.P. (orthorh.-h.) 483-503 K
// a-AXIS
// b-AXIS
// c-AXIS
POLYCRYSTALLINE
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 88

SPECIFICATION TABLE 88. THERMAL LINEAR EXPANSION OF TRIURANIUM OCTAOXIDE U_3O_8

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	222	Gronvold, F.	1955	X	293-1223	O/U = 2.50	U_3O_{8-x} crystal specimen; orthorhombic structure; sintered; lattice expansion measured along a-axis; lattice constant reported at 293.2 K is 6.734 Å.
2	222	Gronvold, F.	1955	X	293-1223	O/U = 2.50	The above specimen; lattice expansion measured along b-axis; lattice constant reported at 293.2 K is 3.966 Å.
3	222	Gronvold, F.	1955	X	293-1223	O/U = 2.50	The above specimen; lattice expansion measured along c-axis; lattice constant reported at 293.2 K is 4.145 Å.
4	222	Gronvold, F.	1955	X	293-1046	O/U = 2.60	Similar to the above specimen; lattice expansion measured along a-axis; lattice constant reported at 293.2 K is 6.734 Å.
5	222	Gronvold, F.	1955	X	293-1046	O/U = 2.60	The above specimen; lattice expansion measured along b-axis; lattice constant reported at 293.2 K is 3.966 Å.
6	222	Gronvold, F.	1955	X	293-1046	O/U = 2.60	The above specimen; lattice expansion measured along c-axis; lattice constant reported at 293.2 K is 4.144 Å.
7	222	Gronvold, F.	1955	X	293-1016	O/U = 2.667	Similar to the above specimen; lattice expansion measured along a-axis; lattice constant reported at 293.2 K is 6.720 Å.
8	222	Gronvold, F.	1955	X	293-1016	O/U = 2.667	The above specimen; lattice expansion measured along b-axis; lattice constant reported at 293.2 K is 3.983 Å.
9	222	Gron old, F.	1955	X	293-1016	O/U = 2.667	The above specimen; lattice expansion measured along c-axis; lattice constant reported at 293.2 K is 4.146 Å.
10	319	Hoekstra, H.R., Siegel, S., Fuchs, L.H., and Katz, J.J.	1955	X	293-645	Orthorhombic	Orthorhombic single crystal; obtained from $UO_{2.64}$ by heating $UO_{2.64}$ in oxygen to 1023 K; unit cell parameter expansion measured along a-axis; 6.6835 Å reported at 293 K.
11	319	Hoekstra, H.R., et al.	1955	X	293-645	Orthorhombic	The above specimen; unit cell parameter expansion measured along b-axis; 11.9259 Å reported at 293 K.
12	319	Hoekstra, H.R., et al.	1955	X	293-645	Orthorhombic	The above specimen; unit cell parameter expansion measured along c-axis; 4.1389 Å reported at 293 K.
13*	319	Hoekstra, H.R., et al.	1955	X	717-873	Hexagonal	The above specimen; U_3O_8 approaching hexagonal or pseudo-hexagonal symmetry from 718 K up to approximately 873 K; unit cell parameter expansion measured along a-axis; only data on unit cell parameter reported.
14*	319	Hoekstra, H.R., et al.	1955	X	717-873	Hexagonal	The above specimen; only data on unit cell parameter along c-axis reported.
15	650	Momin, A.C., Mathews, M.D., and Karkhanavala, M.D.	1971	L	293-673	O/U = 2.67	Pellet specimen 10 x 12.5 mm; prepared by dry-pressing (4000 Kg/cm²) the finely powdered (-300 mesh); sintered in air for 25 hr at different temperatures in the range 250 to 1000 C depending upon stability range of the phase; heating rate 4 C per min; specimen of orthorhombic structure; transition temperature at 210 ± 5 C for orthorhombic to the hexagonal forms.
16	650	Momin, A.C., et al.	1971	L	293-870	O/U = 2.66	Similar to the above specimen.
17	650	Momin, A.C., et al.	1971	L	293-1070	O/U = 2.65	Similar to the above specimen.
18	650	Momin, A.C., et al.	1971	L	293-1068	O/U = 2.64	Similar to the above specimen.
19	650	Momin, A.C., et al.	1971	X	305-1283		Stoichiometric U_3O_8 (-200 mesh) obtained by heating UO_2 at 400 C for a period of 20 hr; measurements carried out in air; cell dimensions of both orthorhombic and hexagonal forms were calculated; transition of orthorhombic U_3O_8 to hexagonal form occurs at 210 C and complete at 230 C; cell dimension measured along a-axis; 6.715 Å reported at 305 K; 6.711 Å at 293 K determined by graphical extrapolation.

* Not shown in figure.

SPECIFICATION TABLE 88. THERMAL LINEAR EXPANSION OF TRIURANIUM OCTAOXIDE U_3O_8 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
20	650	Momin, A.C., Mathews, M.D., and Karkhanavala, M.D.	1971	X	305-477		The above specimen; cell dimension measured along b-axis; 11.950 Å reported at 305 K; 11.966 Å at 293 K determined by graphical extrapolation.
21	650	Momin, A.C., et al.	1971	X	305-1277		The above specimen; cell dimension measured along c-axis; 4.1455 Å reported at 305 K; 4.1463 Å at 293 K determined by graphical extrapolation.
22	651	Schaekevs, J.M. and Lovell, G.H.B.	1969	L	293-1373		Rod specimen 10 cm long, 1 cm diameter; fired for 2 hr in oxygen at 1400 C; 95.5% of theoretical density.

DATA TABLE 88. THERMAL LINEAR EXPANSION OF TRIURANIUM OCTAOXIDE U_3O_8

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
293	0.000
523	0.267
767	0.282
1001	0.446
1223	0.802

CURVE 2

T	$\Delta L/L_0$
293	0.000*
523	0.101
767	0.328
1001	0.378
1223	0.429

CURVE 3

T	$\Delta L/L_0$
293	0.000*
523	-0.024
767	-0.048
1001	0.024
1223	-0.121

CURVE 4

T	$\Delta L/L_0$
293	0.000*
519	0.223
795	0.728
1046	0.965

CURVE 5

T	$\Delta L/L_0$
293	0.000*
519	-0.126
795	-0.177
1046	-0.126

CURVE 6

T	$\Delta L/L_0$
293	0.000*
519	-0.072
795	-0.145
1046	-0.193

CURVE 7

T	$\Delta L/L_0$
293	0.000*
478	0.774
768	0.997
1016	1.131

CURVE 8

T	$\Delta L/L_0$
293	0.000*
478	-0.778
768	-1.130
1016	-0.577

CURVE 9

T	$\Delta L/L_0$
293	0.000*
478	-0.024
768	-0.265
1016	-0.169

CURVE 10

T	$\Delta L/L_0$
293	0.0000*
323	0.2657
373	0.7227
423	1.1019
473	1.4080
523	1.6440
573	1.7873
623	1.8844
645	1.9008

CURVE 11

T	$\Delta L/L_0$
293	0.0000*
323	-0.1456
373	-0.3815
423	-0.5556
473	-0.7372
523	-0.8878
573	-1.0192
623	-1.1539
645	-1.2016

CURVE 12

T	$\Delta L/L_0$
293	0.0000*
323	-0.0634
373	-0.1478
423	-0.2240
473	-0.2799
523	-0.3317
573	-0.3783
623	-0.4224
645	-0.4398

CURVE 13*

T	a(Å)
717	6.7918 h.
723	6.7920
773	6.7935
823	6.7954
873	6.7967

CURVE 14*

T	c(Å)
717	4.1202 h.
723	4.1203
773	4.1205
823	4.1207
873	4.1208
878	4.1208

CURVE 15

T	$\Delta L/L_0$
293	0.0000*
370	-0.0057
422	-0.0180*
471	-0.0319*
524	-0.0506*
572	-0.0594*
618	-0.0605*
673	-0.0605*

CURVE 16

T	$\Delta L/L_0$
293	0.000*
325	-0.010
372	-0.015
423	-0.021
472	-0.033
524	-0.050
572	-0.057
621	-0.060
670	-0.057
723	-0.053
770	-0.045
819	-0.040
870	-0.038

CURVE 17

T	$\Delta L/L_0$
293	0.0000*
373	-0.0043*
423	-0.0154*
472	-0.0284*
523	-0.0459*
571	-0.0545
620	-0.0558*
670	-0.0542
724	-0.0505*
770	-0.0411*
821	-0.0342*
868	-0.0263
919	-0.0035
969	-0.0022
1018	0.0069
1070	0.0087

CURVE 18

T	$\Delta L/L_0$
293	0.0000*
325	-0.0060*
375	-0.0193*
423	-0.0266*
470	-0.0371*
526	-0.0414*
572	-0.0465*
624	-0.0495
670	-0.0465*
719	-0.0419
771	-0.0316*

CURVE 18 (cont.)

T	$\Delta L/L_0$
822	-0.0208
870	0.0000
922	0.0188
969	0.0332
1018	0.0521
1068	0.0667

CURVE 19

T	$\Delta L/L_0$
305	0.057 orthorh.
380	0.299
479	0.957

T	a(Å)
531	6.781* h.
582	6.782*
680	6.798*
882	6.814*
981	6.819*
1182	6.833*
1283	6.844*

CURVE 20

T	$\Delta L/L_0$
305	-0.132
380	-0.443
477	-1.176

CURVE 21

T	$\Delta L/L_0$
305	-0.019 orthorh.
376	-0.041
478	-0.072

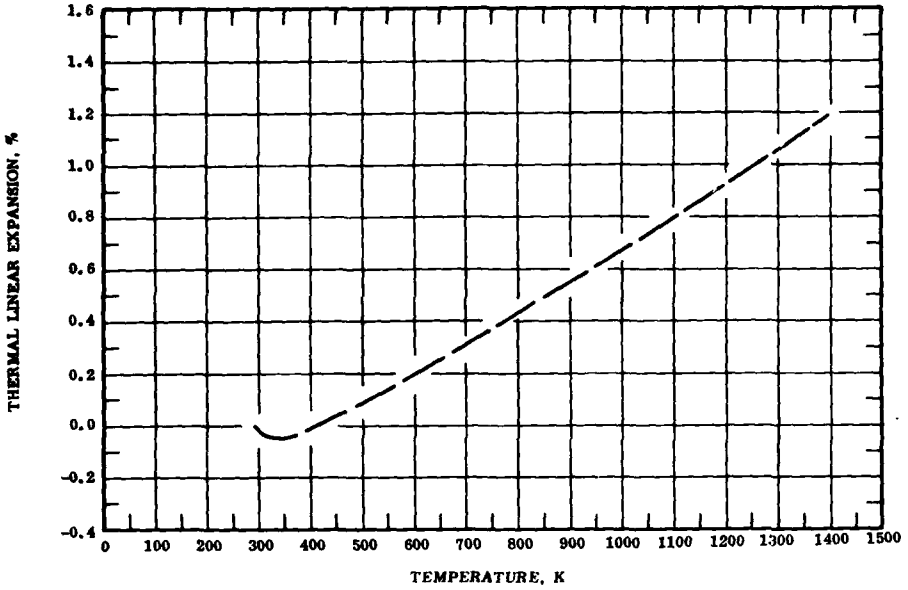
T	c(Å)
528	4.139* h.
576	4.138*
677	4.134*
876	4.129*
980	4.128*
1173	4.124*
1277	4.122*

CURVE 22

T	$\Delta L/L_0$
293	0.00*
323	0.00*
373	-0.01*
423	-0.03
473	-0.05
523	-0.06
573	-0.08
623	-0.09
673	-0.09
723	-0.09
773	-0.09
823	-0.08
873	-0.07
923	-0.06
973	-0.04
1023	-0.02
1073	0.01
1123	0.04
1173	0.07
1223	0.10
1273	0.13
1323	0.16
1373	0.19

*Not shown in figure.

FIGURE AND TABLE NO. 89R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF TETRAURANIUM NONAOXIDE U_4O_9



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	-20
325	-0.047	-8
350	-0.057	0
375	-0.034	10
400	-0.010	10
450	0.040	10
500	0.090	10
600	0.197	11
700	0.310	12
800	0.426	12
900	0.548	12
1000	0.675	13
1100	0.793	13
1200	0.930	13
1300	1.060	13
1400	1.193	13

REMARKS

The provisional values are based on the data for the stoichiometric, pure samples (curves 1, 3, and 13) and are considered accurate to within ±10%. These values are represented approximately by the following equations:

$$\Delta L/L_0 = 2.047 - 0.012\ T + 1.873 \times 10^{-5}\ T^2 - 2.264 \times 10^{-8}\ T^3 \qquad (293\text{–}350\ K)$$

$$\Delta L/L_0 = -0.331 + 6.205 \times 10^{-4}\ T + 5.047 \times 10^{-7}\ T^2 - 1.216 \times 10^{-10}\ T^3 \qquad (350\text{–}1400\ K)$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±15%.

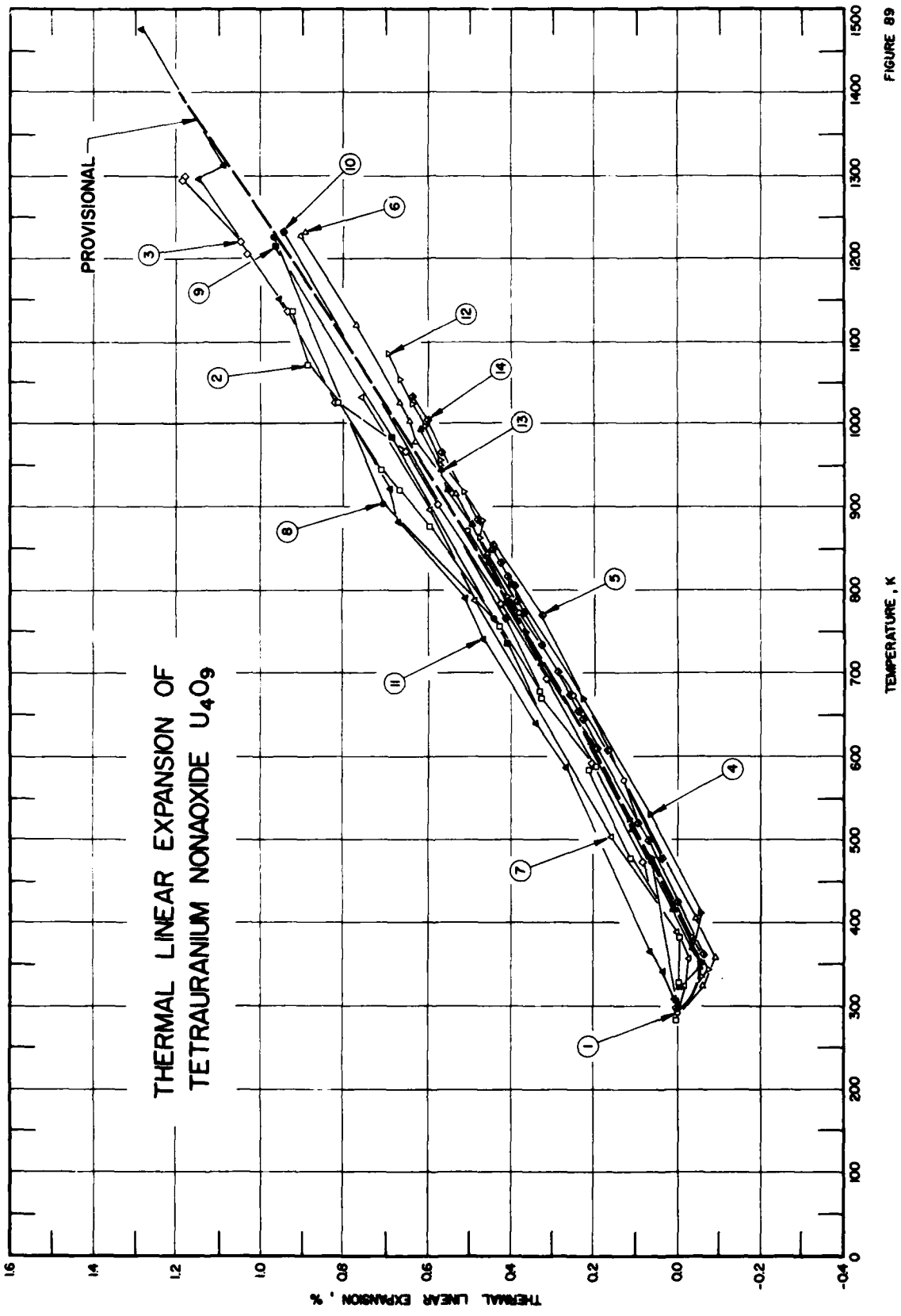

THERMAL LINEAR EXPANSION OF
TETRAURANIUM NONAOXIDE U_4O_9
PROVISIONAL
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
100
1200
1300
1400
1500
1
2
3
4
5
6
7
8
9
10
11
12
13
14

FIGURE 89

SPECIFICATION TABLE 89. THERMAL LINEAR EXPANSION OF TETRAURANIUM NONAOXIDE U_4O_9

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	150	Vaughan, D.A. and Schwartz, C.M.	1962	X	293-873	O/U = 2.24	Specimen 0.1 mm diameter, 1-2 mm long; protected from oxidation by encapsulation in evacuated and sealed vitreous silica tube; lattice parameter expansion measured; 5.4433 Å reported at 293 K.
2	223	Ferguson, I.F. and Street, R.S.	1963	X	283-1137	O/U = 2.235	U_4O_{9-y} powder specimen; placed in silica capillary; heated with specpure platinum; cube cell edge expansion measured; 5.4427 Å reported at 293.2 K.
3	223	Ferguson, I.F. and Street, R.S.	1963	X	293-1299	O/U = 2.235	Similar to the above specimen except platinum wire mound onto capillary; cube cell edge expansion measured; 5.4434 Å reported at 293.2 K.
4	222	Gronvold, F.	1955	X	293-809	O/U = 2.10	Specimen prepared by mixing UO_2 and U_3O_8 to constant weight at 1073 K; consists of two phases of UO_2 and U_4O_9 up to 823 K; lattice expansion measured; 5.4468 Å reported at 293.2 K.
5	222	Gronvold, F.	1955	X	293-857	O/U = 2.15	Similar to the above specimen; two-phase preparation between 293 and 853 K; lattice expansion measured; 5.4463 Å reported at 293.2 K.
6	222	Gronvold, F.	1955	X	293-1233	O/U = 2.20	Similar to the above specimen; two-phase preparation between 293 and 1233 K; lattice expansion measured; 5.4465 Å reported at 293.2 K.
7	222	Gronvold, F.	1955	X	293-1033	O/U = 2.25	Similar to the above specimen; one-phase preparation; lattice expansion measured; 5.4411 Å reported at 293.2 K.
8	222	Gronvold, F.	1955	X	769-1229	O/U = 2.30	Specimen prepared by mixing U_3O_8 and U_4O_9; sintered until nearly homogeneous; lattice expansion measured; 5.4651 Å reported at 769.2 K; linear expansion calculated by assuming 5.4411 Å at 293.2 K.
9	222	Gronvold, F.	1955	X	293-1218	O/U = 2.40	Similar to the above specimen; lattice expansion measured; 5.4416 Å reported at 293.2 K.
10	222	Gronvold, F.	1955	X	293-1223	O/U = 2.50	Similar to the above specimen; lattice expansion measured; 5.4423 Å reported at 293.2 K.
11	138, 142	Roth, J. and Halteman, E.K.	1963	X	307-1533	O/U = 2.24	Lattice expansion measured on specimen having oxygen-to-metal ratio of 2.24 using ThO_2 as internal standard for temperature determination; lattice parameter reported at 307.2 K is 5.4677 Å; 5.4675 Å at 293.2 K determined by graphical extrapolation.
12	649	Naito, K., Tsuji, T., and Matsui, T.	1973	X	293-1085	O/U = 2.250	Powder sample prepared by mixing U_3O_8 and UO_2 powders in O/U compositions; mixtures pressed in 7 mm circular die at about 2000 kg/cm² without any binder in argon atmosphere in glove box to yield pellet 7 mm diameter and 2 mm thick; annealed at about 1020 C for 300 hr and then cooled slowly to room temperature in 300 hr; low-temperature transition at 66 C in the range from -29 to 70 C, high-temperature transition at 620 C in the range from 350 to 860 C.
13	649	Naito, K., et al.	1973	X	293-992	O/U = 2.240	Similar to the above specimen; low-temperature transition at 72 C in the range from -24 to 77 C, high-temperature transition at 560 C in the range from 300 to 810 C.
14	649	Naito, K., et al.	1973	X	293-1034	O/U = 2.228	Similar to the above specimen; low-temperature transition at 77 C in the range from -16 to 84 C, high-temperature transition at 540 C in the range from 550 to 760 C.

DATA TABLE 89. THERMAL LINEAR EXPANSION OF TETRAURANIUM NONAOXIDE U_4O_9

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.0000
473	0.0642
573	0.1285
673	0.2498
773	0.3766
873	0.5015
CURVE 2	
283	0.0018
293	0.0000*
328	-0.0018
383	-0.0073
476	0.1120
582	0.2131
588	0.1965
670	0.3252
678	0.3270
758	0.4280
877	0.5971
920	0.6669
945	0.7092
1028	0.8139
1071	0.8874
1137	0.9241
CURVE 3	
293	0.0000*
471	0.0845
591	0.2039
691	0.3141
783	0.4225
904	0.5750
966	0.6558
1058	0.8193
1137	0.9350
1206	1.0306
1221	1.0489
1295	1.1812
1299	1.1794
CURVE 4	
293	0.0000*
411	-0.0550
533	0.0642
670	0.2258
809	0.4002
CURVE 5	
293	0.0000*
477	0.0367
607	0.1670
771	0.3231
857	0.4425
CURVE 6	
293	0.0000*
325	-0.0605
359	-0.0881
405	-0.0422
846	0.4388
916	0.5342
979	0.6279
1004	0.6407
1028	0.6664
1120	0.7674
1228	0.9070
1233	0.8941
CURVE 7	
293	0.0000*
325	-0.0147
359	-0.0257
388	0.0036
503	0.1580
786	0.4870
896	0.5991
1033	0.7535
CURVE 8	
769	0.4410
905	0.7075
1229	0.9685
CURVE 9	
293	0.0000*
737	0.4098
983	0.6817
1218	0.9647
CURVE 10	
293	0.0000*
767	0.4115
1223	0.9426
CURVE 11	
307	0.0037
310	0.0128
343	0.0366
368	0.0713
588	0.2670
640	0.3402
742	0.4701
790	0.5066
883	0.6676
923	0.6950
1153	0.9602
1296	1.1468
1313	1.0901
1478	1.2913
1533	1.3425*
CURVE 12	
293	0.000*
336	-0.057
345	-0.074
383	-0.035
478	0.063
527	0.118
614	0.204
751	0.360
791	0.410
865	0.476
884	0.469
919	0.511
957	0.566
998	0.605
1026	0.634
1054	0.663
1085	0.695
CURVE 13	
293	0.000*
324	-0.002
349	-0.053
353	-0.055
371	-0.037
416	0.013
515	0.108
613	0.208
712	0.325
786	0.413
835	0.456
880	0.496
921	0.548
944	0.566
992	0.617
CURVE 14	
293	0.000*
297	0.006
362	-0.062
424	0.002
500	0.073
521	0.096
609	0.191
645	0.224
654	0.235
673	0.257
701	0.285
736	0.323
774	0.367
786	0.380
807	0.389
819	0.406
834	0.422
852	0.446
886	0.479
966	0.562
1006	0.600
1034	0.633

*Not shown in figure.

SPECIFICATION TABLE 90. THERMAL LINEAR EXPANSION OF VANADIUM DIOXIDE VO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	224	Rao, K.V.K., Naidu, S.V.N., and Iyengar, L.	1967	X	351-688		Powder specimen, obtained from Matsushita Electric Industrial Co., Japan; prepared by filling in fine thin-salled pyrex capillary VO_2 undergoes semiconductor to metal transition from monoclinic to rutile phase at about 340 K; expansion measured with Cu radiation along a-axis of tetragonal phase; lattice parameter reported at 351.2 K is 4.5534 Å; this curve is here reported using the first temperature as reference temperature at which $\Delta L/L_0 = 0$; coefficient of thermal linear expansion also reported.
2*	224	Rao, K.V.K., et al.	1967	X	351-688		The above specimen; expansion measured along c-axis of tetragonal phase; lattice parameter reported at 351.2 K is 2.8502 Å; this curve is here reported using the first temperature as reference temperature at which $\Delta L/L_0 = 0$; coefficient of thermal linear expansion also reported.
3*	170	Kirchner, H.P.	1969	X	373-653		Specimen obtained from City Chemical Corp; transformation of monoclinic phase to tetragonal phase at about 340 K; expansion measured along a-axis of tetragonal phase in helium atmosphere; this curve is here reported using the first temperature as reference temperature at which $\Delta L/L_0 = 0$.
4*	170	Kirchner, H.P.	1969	X	373-652		The above specimen; expansion measured along c-axis of tetragonal phase; this curve is here reported using the first temperature as reference temperature at which $\Delta L/L_0 = 0$.
5*	334	King, B.W. and Subes, L.L.	1955	L	300-723		Tetragonal structure specimen; prepared by heating NH_4VO_3 in platinum boat in purified argon; product which contained 85-92% V_2O_4 and 8-15% V_2O_5 obtained with calcination temperatures between 699 and 1366 K; purity of original product improved by washing with ammonium hydroxide solution of pH 8-10; after drying in argon at 383 K specimen contained about 2% unidentified cryptocrystalline birefringent phase examined by both x-ray and petrographic means; melting point 1818 K; data from smoothed curve; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

*No figure given.

DATA TABLE 90. THERMAL LINEAR EXPANSION OF VANADIUM DIOXIDE VO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*, †		CURVE 2*, †		CURVE 3*, †		CURVE 5*, †	
351	0.0000	351	0.0000	373	0.000	300	0.000
369	0.0109	369	0.0386	473	0.097	323	0.023
405	0.0329	405	0.1684	573	0.173	373	0.060
438	0.0373	438	0.2351	653	0.256	423	0.088
457	0.0549	457	0.3052			473	0.110
490	0.0703	490	0.3508	CURVE 4*, †		523	0.133
540	0.0769	540	0.4736			573	0.160
588	0.1252	588	0.6035	373	0.000	623	0.187
688	0.1537	688	0.8280	473	0.170	673	0.217
				573	0.448	723	0.245
				652	0.649		

DATA TABLE 90. COEFFICIENT OF THERMAL LINEAR EXPANSION OF VANADIUM DIOXIDE VO_2

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1*	
373	5.22
413	4.94
453	4.67
493	4.67
533	4.67
573	4.28
613	3.95
653	4.28
CURVE 2*	
373	26.93
413	26.14
453	25.08
493	24.47
533	23.86
573	23.24
613	22.37
653	22.37

* No figure given.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

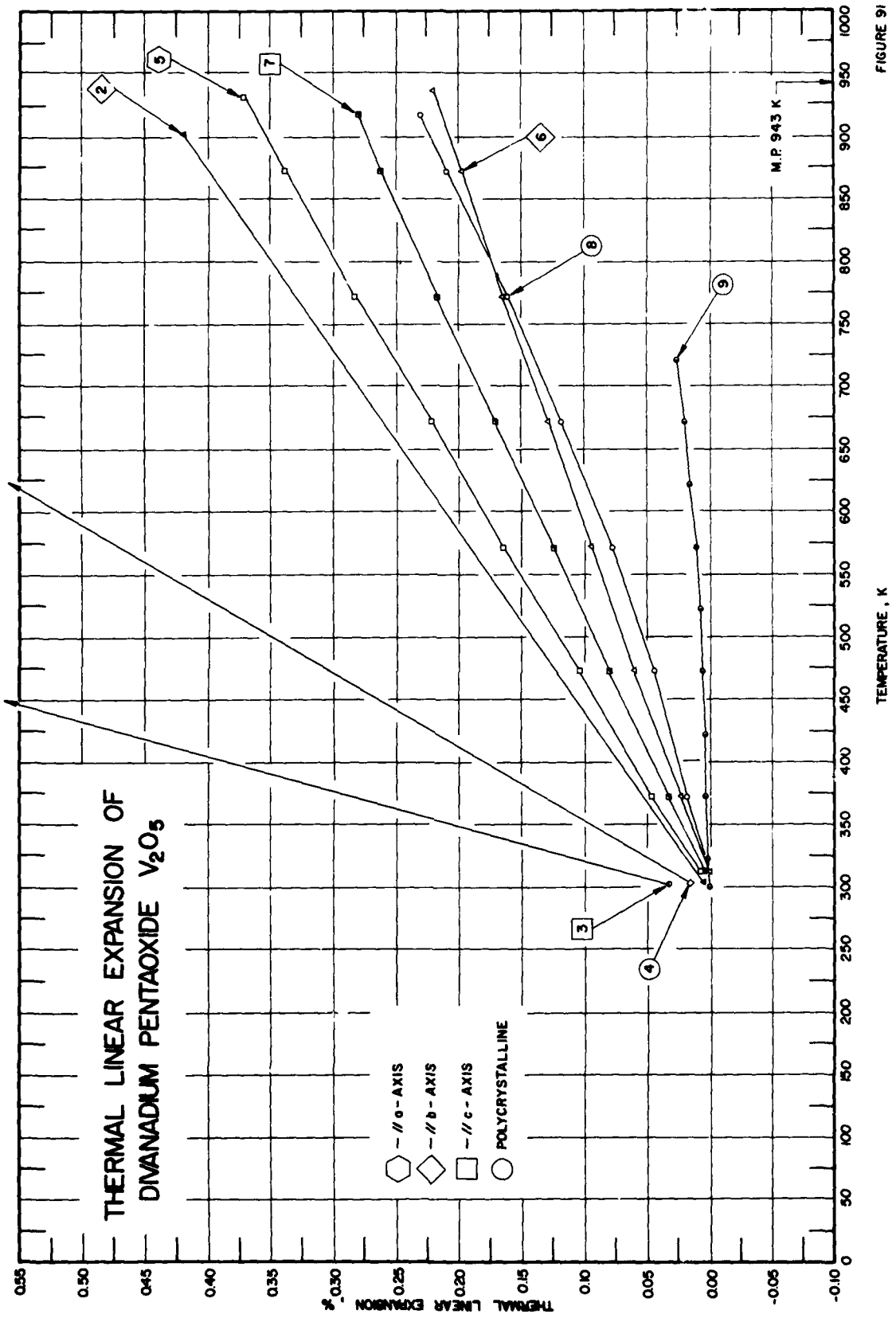

THERMAL LINEAR EXPANSION OF DIVANADIUM PENTAOXIDE V_2O_5
// a - AXIS
// b - AXIS
// c - AXIS
POLYCRYSTALLINE
M.P. 943 K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
2
3
4
5
6
7
8
9

FIGURE 91

SPECIFICATION TABLE 91. THERMAL LINEAR EXPANSION OF DIVANADIUM PENTAOXIDE V_2O_5

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	225	Corvin, I. and Cartz, L.	1965	X	303, 902		Fisher reagent grade, orthorhombic structure specimen; expansion measured with CuKγ radiation along a-axis; temperature calibrated with platinum powder intimately mixed with specimen.
2	225	Corvin, I. and Cartz, L.	1965	X	303, 902		The above specimen; expansion measured along b-axis.
3	225	Corvin, I. and Cartz, L.	1965	X	303, 902		The above specimen; expansion measured along c-axis.
4	225	Corvin, I. and Cartz, L.	1965	X	303, 902		Randomly oriented polycrystalline specimen; calculated by using the above data.
5	333	Brown, J.J., Jr.	1964	X	313-932		Annealed platinum powder used as internal standard; expansion measured along a-axis; data from smoothed curve; zero-point correction of 0.009% determined by graphical extrapolation.
6	333	Brown, J.J., Jr.	1964	X	313-939		The above specimen; expansion measured along b-axis; data from smooth curve; zero-point correction of 0.001% determined by graphical extrapolation.
7	333	Brown, J.J., Jr.	1964	X	313-919		The above specimen; expansion measured along c-axis; data from smoothed curve; zero-point correction of 0.006% determined by graphical extrapolation.
8	333	Brown, J.J., Jr.	1964		313-919		Randomly oriented polycrystalline specimen; data from smoothed curve; zero-point correction of 0.005% determined by graphical extrapolation.
9	334	King, B.W. and Suber, L.L.	1955	L	300-723		*98-100* V_2O_5, *remainder almost entirely lower oxides of* vanadium; obtained from Vanadium Corporation of America; prepared by heating NH_4VO_3 in oxygen in platinum boat at 1003 K; m.p. 943 K; data from smoothed curve; zero-point correction of 0.001% determined by graphical extrapolation.

* Not shown in figure.

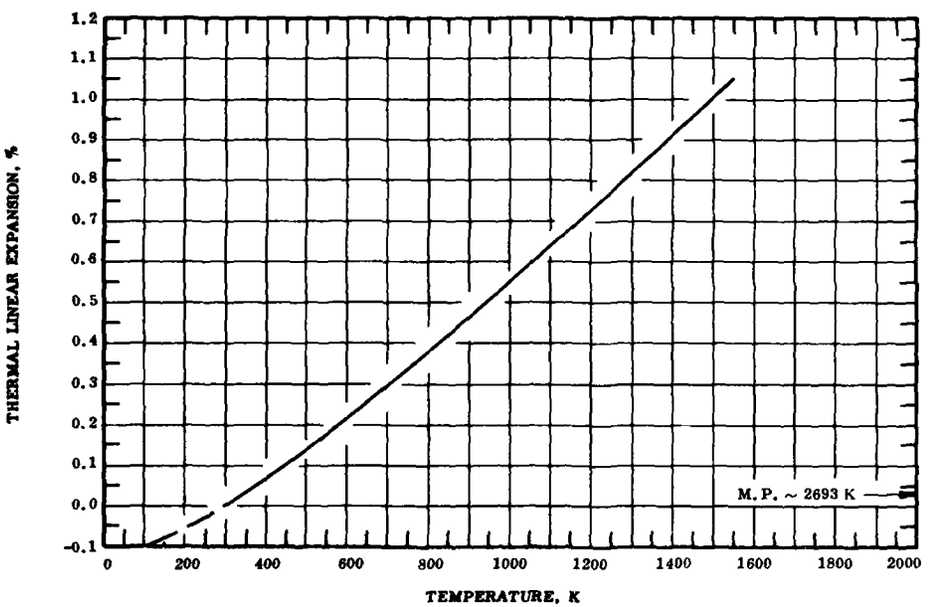
DATA TABLE 91. THERMAL LINEAR EXPANSION OF DIVANADIUM PENTAOXIDE V_2O_5

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
303	0.0095
902	0.58
CURVE 2	
303	0.0069
902	0.42
CURVE 3	
303	0.0352
902	2.14*
CURVE 4	
303	0.0172
902	1.05*
CURVE 5	
313	0.009
373	0.047
473	0.105
573	0.165
673	0.224
773	0.284
873	0.340
932	0.372
CURVE 6	
313	0.001
373	0.025
473	0.061
573	0.095
673	0.130
773	0.165
873	0.198
939	0.221
CURVE 7	
313	0.006
373	0.035
473	0.081
573	0.125
673	0.171
773	0.218
873	0.261
919	0.280
CURVE 8	
313	0.005*
373	0.020
473	0.045
573	0.079
673	0.118
773	0.162
873	0.210
919	0.232
CURVE 9	
300	0.001
323	0.003
373	0.004
423	0.004
473	0.006
523	0.008
573	0.012
623	0.017
673	0.021
723	0.027

* Not shown in figure.

FIGURE AND TABLE NO. 92R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF YTTERBIUM OXIDE Yb_2O_3



RECOMMENDED VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

T	$\Delta L/L_0$	α
100	-0.098†	5.0
150	-0.080†	5.3
200	-0.055†	5.6
250	-0.026†	5.9
293	0.000	6.1
400	0.072	6.7
500	0.142	7.2
600	0.218	7.6
700	0.296	7.9
800	0.378	8.3
900	0.460	8.6
1000	0.550	8.8
1100	0.635	9.0
1200	0.722	9.2
1300	0.815	9.3
1400	0.910	9.4
1500	1.000	9.6
1550	1.055	9.7

†Provisional values.

REMARKS

The recommended values are based on the data for pure samples and are considered accurate to within ±5% at temperatures above 293 K and ±7% at temperatures below 293 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.155 + 4.387 \times 10^{-4}\, T + 3.325 \times 10^{-7}\, T^2 - 7.431 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±7%.

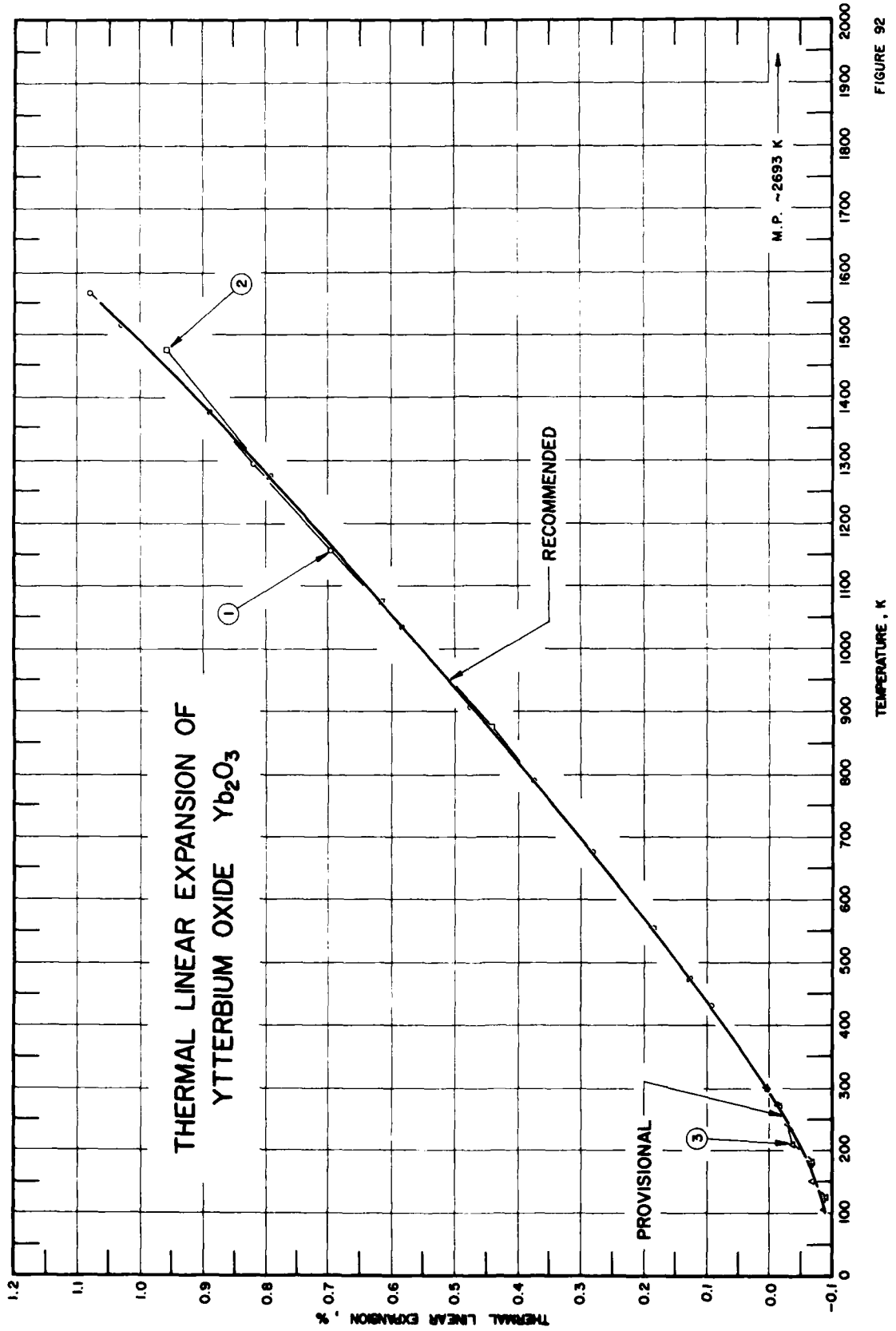

THERMAL LINEAR EXPANSION OF
YTTERBIUM OXIDE Yb_2O_3
RECOMMENDED
PROVISIONAL
M.P. ~2693 K
1
2
3
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 92

SPECIFICATION TABLE 92. THERMAL LINEAR EXPANSION OF YTTERBIUM OXIDE Yb_2O_3

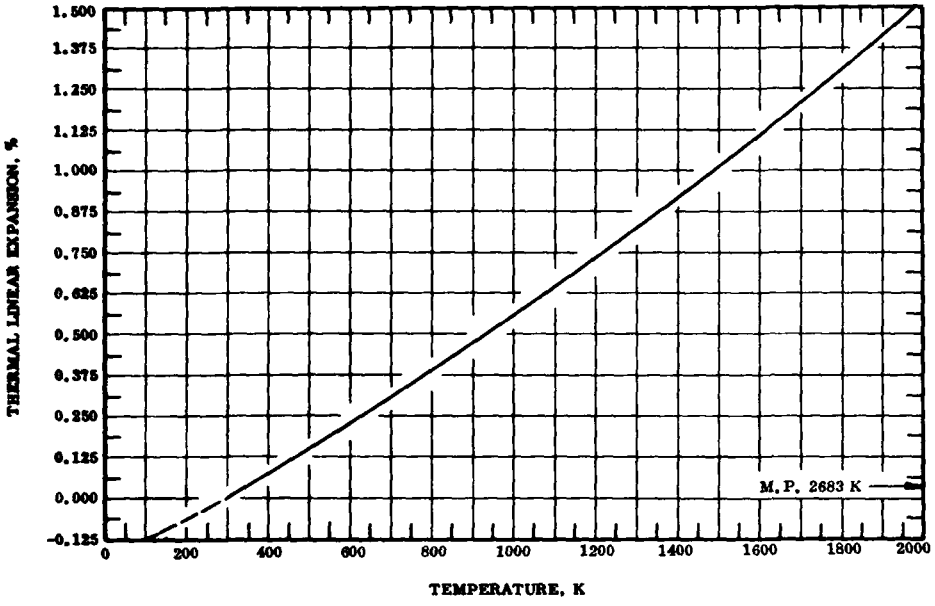
Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	68	Stecura, S. and Campbell, W.J.	1961	X	273-1566		99.9 pure; specimen obtained from Michigan Chemical Co.; sintered at 1573 K for 24 hr; packed in alumina holder, sintered at 1673 K for 12 hr, cooled to 523 K, stored in vacuum; reported error ± 2%; unit cell parameter reported at 273.2 K is 10.4325 Å; zero-point correction of -0.013% determined by graphical interpolation.
2	99	Brown, W.R. and Kirchner, N.P.	1961	X	298-1473		Specimen obtained from Research Chemical, Inc.; expansion measured with CrKα radiation; lattice parameter reported at 298.2 K is 10.4344 Å; 10.4340 Å at 293.2 K determined by graphical extrapolation.
3	177	Davenport, J.C.	1965	X	300-104		99.9 pure; specimen obtained from Research Chemical Inc.; prepared in form of thin disk of 1 cm diameter with lucite cement as binder; unit cell parameter reported at 300 K is 10.4333 Å; 10.4324 Å at 293 K determined by graphical interpolation; expansion measured with decreasing temperature.

DATA TABLE 92. THERMAL LINEAR EXPANSION OF YTTERBIUM OXIDE Yb_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 3	
273	-0.013	300	0.0086
299	0.004	270	-0.0268
431	0.094	240	-0.0297
553	0.187	210	-0.0383
674	0.281	180	-0.0671
789	0.375	150	-0.0671
907	0.478	124	-0.0901
1033	0.584	104	-0.0863
1157	0.697		
1294	0.820		
1373	0.890		
1515	1.030		
1566	1.080		
CURVE 2			
298	0.0038		
473	0.1284		
673	0.2798		
873	0.4418		
1073	0.6153		
1273	0.7936		
1473	0.9689		

FIGURE AND TABLE NO. 93R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF YTTRIUM OXIDE Y_2O_3



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
100	-0.137†	5.6
150	-0.102†	6.5
200	-0.066†	7.1
250	-0.306†	7.2
293	0.000	7.3
400	0.079	7.4
500	0.154	7.6
600	0.230	7.8
700	0.309	7.9
800	0.388	8.1
900	0.470	8.3
1000	0.556	8.5
1100	0.640	8.8
1200	0.730	9.0
1300	0.823	9.2
1400	0.916	9.5
1500	1.010	9.7
1600	1.110	10.0
1700	1.210	10.2
1800	1.315	10.5
1900	1.420	10.8
2000	1.540	11.1

† Provisional values.

REMARKS

The recommended values are based on the data for pure samples (curves 6, 7 and 10) and are considered accurate to within ± 5% at temperatures above 293 K and ± 7% below 293 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.206 + 6.849 \times 10^{-4}\, T + 6.336 \times 10^{-6}\, T^2 + 1.438 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ± 7%.

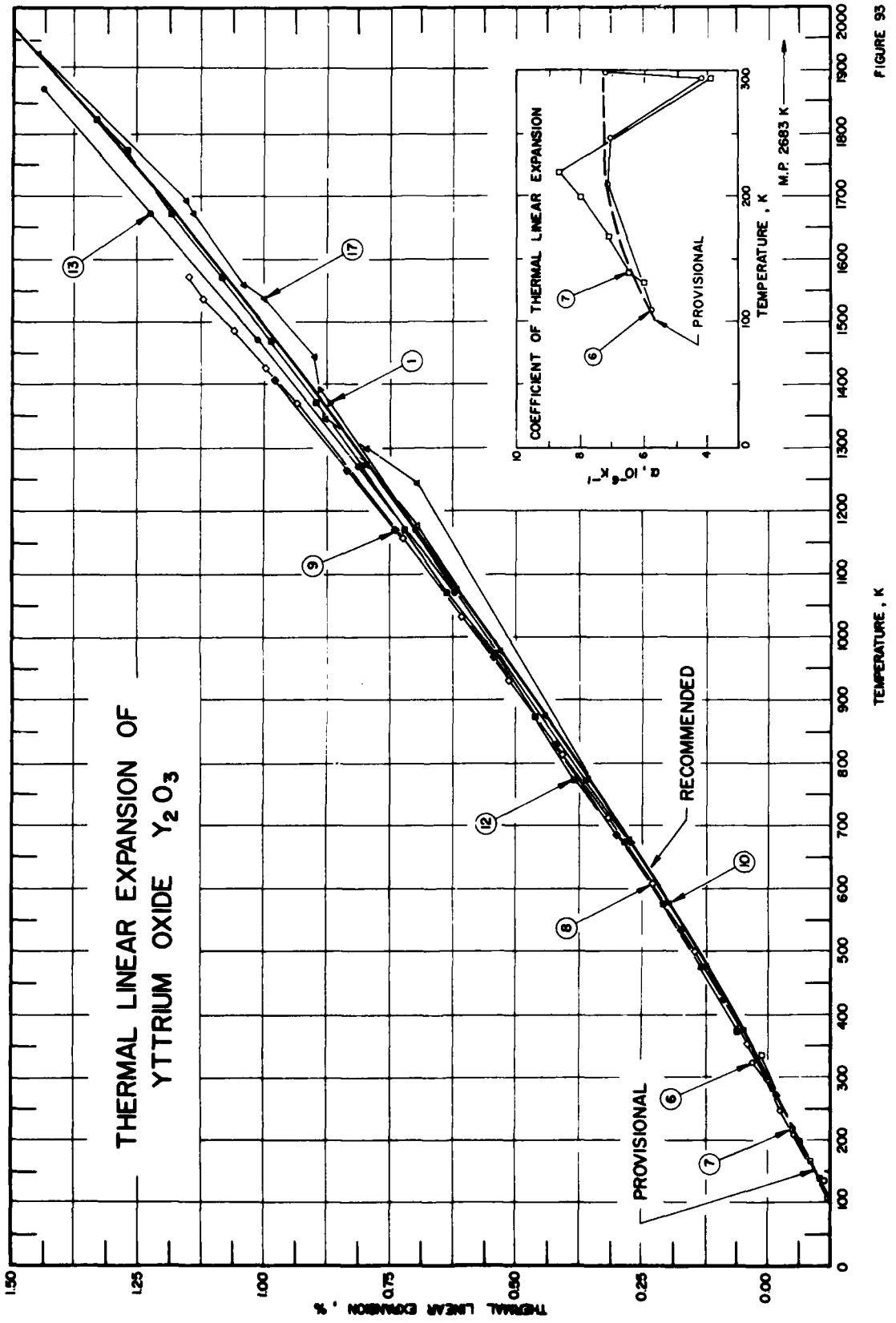

THERMAL LINEAR EXPANSION OF
YTTRIUM OXIDE Y_2O_3
RECOMMENDED
PROVISIONAL
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10^{-6} K^{-1}
PROVISIONAL
TEMPERATURE , K
M.P. 2683 K

FIGURE 93

SPECIFICATION TABLE 93. THERMAL LINEAR EXPANSION OF YTTRIUM OXIDE Y_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	143	Stacy, D.W.	1967	L	298-1393	Y_2O_3 - 1	0.04 Ca, ≤0.04 Ta, ≤0.02 Nd, ≤0.02 Sm, ≤0.02 Th, ≤0.01 Dy, ≤0.01 Yb, ≤0.007 Cu, ≤0.006 Ho, ≤0.006 Si, ≤0.005 Er, ≤0.004 Cr, ≤0.003 Gd, ≤0.003 Ti, and 0.002 Mg; bar specimen 0.125 x 0.25 x 1.0 in.; obtained from Ames Laboratory, Iowa; prepared by pressing powder in steel die to 1000 psi, inverted and repressed to 1200 psi, and finally pressed to 50 000 psi in isostatic press; 75.2% theoretical density; zero-point correction of 0.003% determined by graphical extrapolation.
2*	143	Stacy, D.W.	1967	L	298-1393	Y_2O_3 - 2	Similar to the above specimen; fired at 2423 K under reducing atm; 77.6% theoretical density; zero-point correction of 0.003% determined by graphical extrapolation.
3*	143	Stacy, D.W.	1967	L	298-1393	Y_2O_3 - 3	Similar to the above specimen; fired at 1773 K under hot press atmosphere; 96.7% theoretical density; zero-point correction of 0.003% determined by graphical extrapolation.
4*	143	Stacy, D.W.	1967	L	298-1393	Y_2O_3 - 4	Similar to the above specimen; fired at 2273 K under reducing atmosphere; 94.5% theoretical density; zero-point correction of 0.003% determined by graphical extrapolation.
5*	143	Stacy, D.W.	1967	L	298-1393	Y_2O_3 - 5	Similar to the above specimen; fired at 2273 K under reducing atmosphere; 94.3% theoretical density; zero-point correction of 0.003% determined by graphical extrapolation.
6	226	Klein, P.H. and Croft, W.S.	1967	X	109-324		99.999+ pure; crystal specimen; fabricated by using flame-fusion technique; lattice parameter reported at 299 K is 10.595 Å.
7	226	Klein, P.H. and Croft, W.S.	1967	X	132-335		Similar to the above specimen except 0.608 Nd added.
8	68	Stecuva, S. and Campbell, W.J.	1961	X	273-1573		99.9 pure, major impurities 0.003-0.03 Si, 0.001-0.01 Ca; specimen obtained from Heavy Minerals Co., Tenn.; sintered at 1523 K for 24 hr, packed into alumina holder, sintered at 1623 K for 12 hr, cooled to 423 K and stored in vacuum desiccator; reported error ±1%; lattice constant reported at 273 K is 10.6012 Å.
9	68	Stecuva, S. and Campbell, W.S.	1961	X	1409-421		The above specimen; expansion measured with decreasing temperature.
10	14	Wilfong, R.L., Dominques, L.P., Furlong, L.R., and Finlayson, J.A.	1963	I	298-1274		0.003-0.03 Ca, 0.001-0.01 Al, 0.0003-0.003 Cu, Fe, Mg, Mn, Si, and 0.0001-0.001 Lu, Yb; specimen obtained from Bureau of Mines Station, Reno, Nev.; density 4.2 g cm^{-3}; heating rate 5 C per min; zero-point correction of 0.0030% determined by graphical extrapolation.
11*	14	Wilfong, R.L., et al.	1963	I	298-1273		The above specimen; expansion measured on second test; zero-point correction of 0.0030% determined by graphical extrapolation.
12	227	Fitzsimmons, E.S.	1961	T	298-1823		Specimen 0.25 x 0.25 x 2.25 in.; dry pressed, isostatically compacted, and sintered at 1894 K for 2 hr in hydrogen atmosphere; 96.3% theoretical density; zero-point correction of 0.004% determined by graphical extrapolation.
13	228	Nielsen, T.H. and Leipold, M.H.	1964	L/T	298-2173	LA-15	99.5-99.8 Y_2O_3, and Fe, Ca, Si, Al impurities; polycrystalline specimen; isostatically pressed; expansion measured in 95 wt % oxygen and 5 wt % nitrogen atmosphere; dilatometer to 1273 K, telemicroscope above 1273 K.

*Not shown in figure.

SPECIFICATION TABLE 93. THERMAL LINEAR EXPANSION OF YTTRIUM OXIDE Y_2O_3 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
14*	228	Nielsen, T.H. and Leipold, M.H.	1964	L/T	298-2273	LA-16	Similar to the above specimen; sintered at 1973 K in air; expansion measured in 80-90 wt % argon, 3-4 wt % hydrogen, and 6-16 wt % air atmosphere; dilatometer to 1273 K, telemicroscope above 1273 K.
15*	321	Curtis, C.E.	1956	L	293-1673		Specimen 0.125 in. diameter, 1 in. long; received as fine white powder, contained approximately 0.1 impurities; fabricated from mixture of 1 part of powdered yttria with 2 parts of 80-mesh yttria grog previously calcined at 2073 K, and fired at 2073 K for 2 hr; heating rate 3 C per min; the ordinate in reported figure should be percent thermal expansion; zero-point correction of -0.018%.
16*	336	Kamenetskii, A.B., Gul'ko, N.V., and Gladkaya, N.V.	1970	X	373-1473		99.6 Y_2O_3, 0.16 Al_2O_3, 0.01 Fe_2O_3, 0.005 CaO, trace MgO; specimen prepared by semidry pressing finel dispersed powder of grain size $<2\ \mu$ at 1000 Kg cm^{-2} and fired at 2023 K; data from smoothed curve.
17	652	Stacy, D.W. and Wilder, D.R.	1972	X	293-2212		Y_2O_3 produced as clinker from the calcination of hydrated yttrium oxalate; specimen hot-pressed at 1600 C for 15 min at 3300 psi.

*Not shown in figure.

DATA TABLE 93. THERMAL LINEAR EXPANSION OF YTTRIUM OXIDE Y_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.003*
373	0.051*
473	0.125*
573	0.207*
673	0.291
773	0.365
873	0.441*
973	0.530*
1073	0.611*
1173	0.703
1273	0.788*
1373	0.869
1393	0.888
CURVE 2*	
298	0.003
373	0.048
473	0.119
573	0.201
673	0.287
773	0.366
873	0.444
973	0.523
1073	0.609
1173	0.696
1273	0.778
1373	0.853
1393	0.868
CURVE 3*	
298	0.003
373	0.052
473	0.125
573	0.209
673	0.296
773	0.375
873	0.450
973	0.528
1073	0.613
1173	0.696
1273	0.772
1373	0.849
1393	0.863

T	$\Delta L/L_0$
CURVE 4*	
298	0.003
373	0.048
473	0.113
573	0.189
673	0.269
773	0.349
873	0.433
973	0.519
1073	0.609
1173	0.695
1273	0.773
1373	0.845
1393	0.858
CURVE 5*	
298	0.003
373	0.049
473	0.121
573	0.196
673	0.277
773	0.363
873	0.438
973	0.520
1073	0.606
1173	0.691
1273	0.777
1373	0.864
1393	0.880
CURVE 6‡	
109	-0.117
209	-0.052
246	-0.021
294	0.001
299	0.003
324	0.029
CURVE 7‡	
132	-0.110
138	-0.106
167	-0.087
199	-0.062

T	$\Delta L/L_0$
CURVE 7 (cont.)‡	
218	-0.046
294	0.001*
335	0.014
CURVE 8	
273	-0.014
301	0.005
353	0.042
379	0.059
499	0.150
609	0.233
712	0.319
814	0.410
930	0.513
1032	0.608
1160	0.727
1266	0.833*
1373	0.936
1429	0.998
1489	1.060
1537	1.120
1573	0.150
CURVE 9	
1409	0.979
1266	0.833
1173	0.744
968	0.546
829	0.423
685	0.302
533	0.176
421	0.090
CURVE 10	
298	0.0030*
374	0.0533
475	0.1253
574	0.2002
676	0.2800
775	0.3602
875	0.4437
977	0.5309

T	$\Delta L/L_0$
CURVE 10 (cont.)	
1077	0.6179
1176	0.7060
1274	0.7934
CURVE 11*	
298	0.0030
373	0.0519
475	0.1246
575	0.2009
679	0.2827
774	0.3595
876	0.4442
973	0.5276
1073	0.6146
1172	0.7029
1273	0.7927
CURVE 12	
298	0.004*
373	0.064
473	0.134
573	0.214
673	0.284
773	0.384
873	0.464
973	0.544
1073	0.634
1173	0.724
1273	0.804
1373	0.894
1473	0.984
1573	1.084
1673	1.184
1773	1.274
1823	1.334
CURVE 13	
298	0.003*
473	0.125*
673	0.277*
873	0.444*
1073	0.624

T	$\Delta L/L_0$
CURVE 13 (cont.)	
1273	0.815
1473	1.016
1673	1.227
1873	1.439
2073	1.655*
2173	1.763*
CURVE 14*	
298	0.004
473	0.127
673	0.282
873	0.448
1073	0.626
1273	0.815
1473	1.015
1673	1.221
1873	1.430
2073	1.638
2273	1.839
CURVE 15*	
293	0.000
373	0.043
473	0.111
573	0.179
673	0.261
773	0.344
873	0.431
973	0.518
1073	0.607
1173	0.692
1273	0.778
1373	0.863
1473	0.951
1573	1.037
1673	1.132
CURVE 16*	
373	0.07
473	0.09
573	0.14
673	0.18

T	$\Delta L/L_0$
CURVE 16 (cont.)*	
773	0.23
873	0.28
973	0.34
1073	0.43
1173	0.52
1273	0.62
1373	0.72
1473	0.82
CURVE 17	
293	0.00*
1245	0.70
1300	0.79
1347	0.88
1445	0.90
1538	1.00
1560	1.04
1673	1.14
1691	1.16
1921	1.45
2212	1.78*

*Not shown in figure.

‡Author's data for coefficient of expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

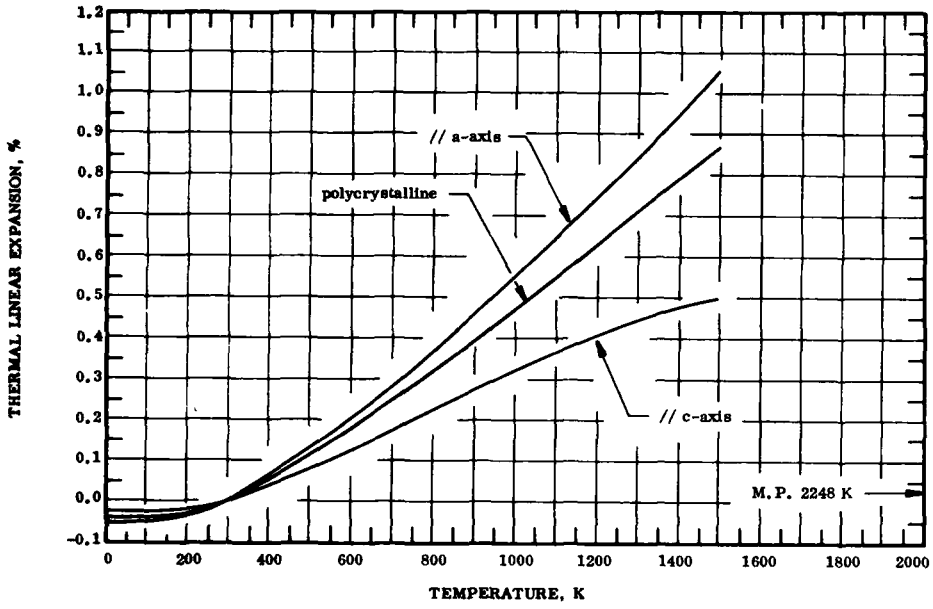
DATA TABLE 93. COEFFICIENT OF THERMAL LINEAR EXPANSION OF YTTRIUM OXIDE Y_2O_3

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 6‡	
109	5.74
209	7.13
246	7.01
294	4.15
299	7.23
324	12.87*
CURVE 7‡	
132	5.98
138	6.44
167	7.08
199	7.96
218	8.66
294	3.83
335	2.59*

*Not shown in figure.
‡Author's data for coefficient of expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 94R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF ZINC OXIDE ZnO



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
10	-0.050	-0.020	-0.040	0.00
25	-0.051	-0.021	-0.041	-0.19
50	-0.052	-0.022	-0.025	-0.56
75	-0.053	-0.024	-0.043	-0.52
100	-0.053	-0.026	-0.044	-0.21
150	-0.052	-0.027	-0.044	1.2
200	-0.038	-0.021	-0.032	2.5
250	-0.020	-0.012	-0.017	3.5
293	0.000	0.000	0.000	4.3
400	0.065	0.040	0.056	5.5
500	0.130	0.080	0.115	6.1
600	0.201	0.125	0.175	6.6
700	0.280	0.173	0.245	7.0
800	0.362	0.222	0.315	7.4
900	0.453	0.272	0.393	7.7
1000	0.545	0.320	0.470	7.8
1100	0.640	0.365	0.548	7.9
1200	0.740	0.405	0.628	8.0
1300	0.840	0.445	0.708	8.0
1400	0.945	0.475	0.787	8.0
1500	1.050	0.495	0.865	8.0

REMARKS

The recommended values for the axial thermal expansion are based on the experimental data reported in curves 4, 6, 8, 10 and 12 for // a-axis and curves 5, 7, 9, 11, 13 and 15 for // c-axis. The values for polycrystalline sample are calculated from the axial values. These values are considered accurate to within ± 5% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.125 + 2.979 \times 10^{-4}\ T + 4.648 \times 10^{-7}\ T^2 - 9.453 \times 10^{-11}\ T^3$ (293-1500 K)

// c-axis: $\Delta L/L_0 = -0.612 + 7.495 \times 10^{-4}\ T + 5.207 \times 10^{-7}\ T^2 - 2.155 \times 10^{-10}\ T^3$ (293-1500 K)

polycrystalline: $\Delta L/L_0 = -0.105 + 2.284 \times 10^{-4}\ T + 4.774 \times 10^{-7}\ T^2 - 1.327 \times 10^{-10}\ T^3$ (293-1500 K)

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 7%.

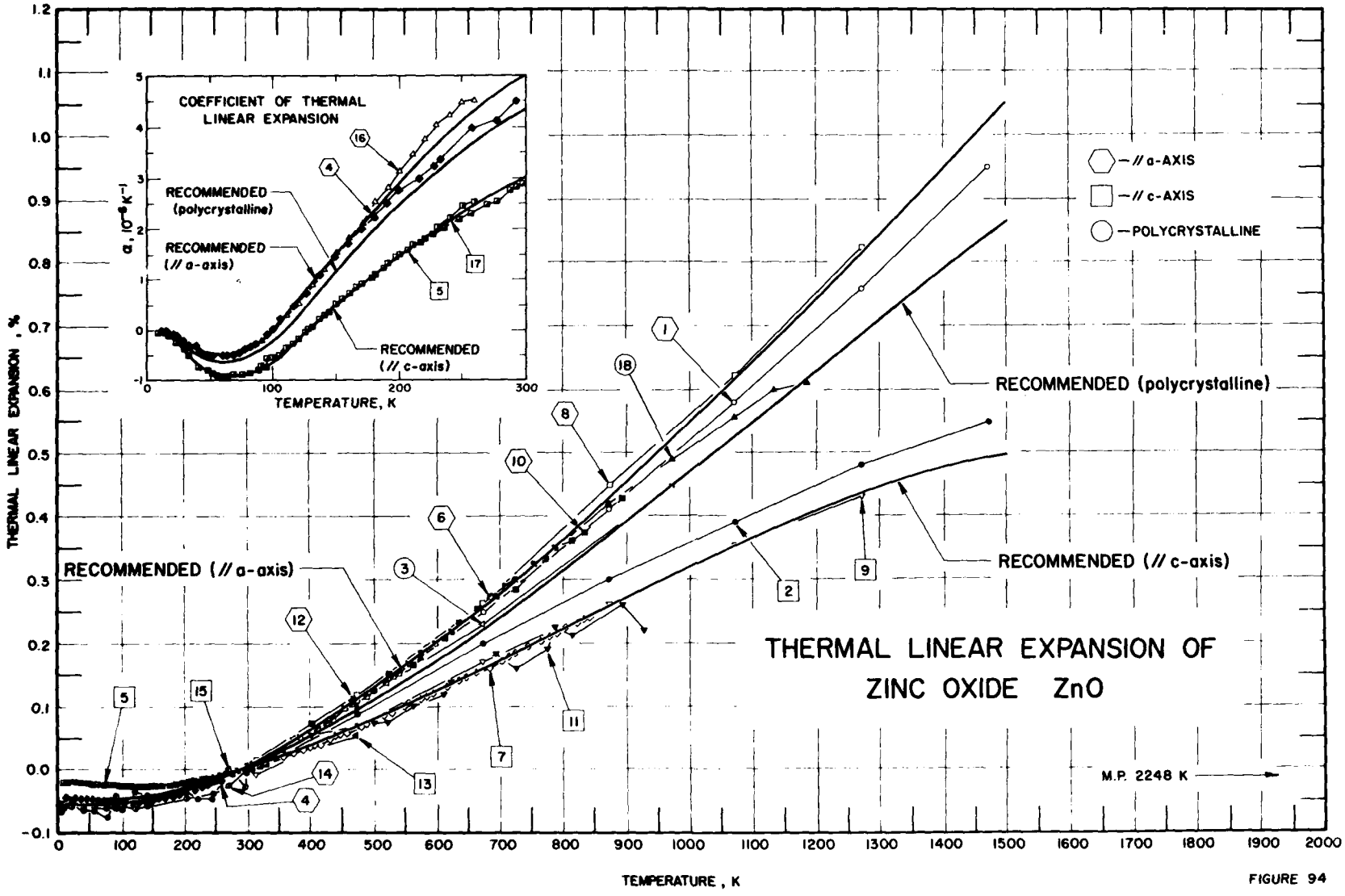

THERMAL LINEAR EXPANSION OF
ZINC OXIDE ZnO
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED (polycrystalline)
RECOMMENDED (// c-axis)
RECOMMENDED (// a-axis)
// a-AXIS
// c-AXIS
POLYCRYSTALLINE
M.P. 2248 K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
α, 10⁻⁶ K⁻¹
RECOMMENDED
(polycrystalline)
RECOMMENDED
(// a-axis)
RECOMMENDED
(// c-axis)
TEMPERATURE, K

FIGURE 94

SPECIFICATION TABLE 94. THERMAL LINEAR EXPANSION OF ZINC OXIDE ZnO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	74	Beals, R. J. and Cook, R. L.	1957	X	309-1473		Reagent grade, powder specimen; has hexagonal-hexagonal lattice; lattice parameter expansion measured along a-axis; linear thermal-expansion coefficient 8.10 x $10^{-6}K^{-1}$ in range 293 to 1473 K; data from smoothed curve; zero-point correction of 0.01% determined by graphical extrapolation.
2	74	Beals, R. J. and Cook, R. L.	1957	X	309-1473		The above specimen; lattice parameter expansion measured along c-axis; linear thermal-expansion coefficient 4.71 x $10^{-6}K^{-1}$ in range 293 to 1473 K; data from smoothed curve; zero-point correction of ±0.00% determined by graphical extrapolation.
3	[illegible]	Wisely, H. R.	1962	L	373-973		Bar specimen, 1/4 x 3/8 x 2 in; formed under pressure 26,000 psi; sintered at 1273 K for 16 hr in air atm.
4	229	Ibach, H.	1969	E	12-321		Single crystal specimen, 1-5 mm thick, 1-5 cm long; transparent, colorless hexagonal prism; expansion measured along a-axis; coefficient of thermal linear expansion integrated by TPRC.
5	229	Ibach, H.	1969	E	9-327		The above specimen; expansion measured along c-axis; coefficient of thermal linear expansion integrated by TPRC.
6	229	Ibach, H.	1969	I	355-754		The above specimen; expansion measured along a-axis with Interferometric method; coefficient of thermal linear expansion integrated by TPRC.
7	229	Ibach, H.	1969	I	357-841		The above specimen; expansion measured along c-axis; coefficient of thermal linear expansion integrated by TPRC.
8	170	Kirchner, H. P.	1969	X	314-1274	Zincite	Commercial specimen; prepared by mixing with mortar and pestle, forcing material through 200-mesh screen; added binder, pressed, fired, and ground; lattice constant expansion measured along a-axis; 3.2484 Å reported at room temperature; zero-point correction of 0.014% determined by graphical extrapolation.
9	170	Kirchner, H. P.	1969	X	314-1273	Zincite	The above specimen; lattice constant expansion measured along c-axis; 5.2040 Å reported at room temperature; zero-point correction of 0.008% determined by graphical extrapolation.
10	230	Khan, A. A.	1968	X	300-892		Extra pure powder specimen; temperature calibrated with silver; lattice parameter expansion measured along a-axis; 3.2500 ± 0.0001Å reported at 300.2 K; 3.2498 Å at 293.2 K determined by graphical extrapolation.
11	230	Khan, A. A.	1968	X	300-892		The above specimen; lattice parameter expansion measured along c-axis; 5.2070 ± 0.0004Å reported at 300.2 K; 5.2068Å at 293.2 K determined by graphical extrapolation.
12	337	Sirdeshmukh, D. B. and Deshpande, V. T.	1967	X	298, 469		Pure quality powder; lattice parameter expansion measured along a-axis.
13	337	Sirdeshmukh, D. B. and Deshpande, V. T.	1967	X	298, 469		The above specimen; lattice parameter expansion measured along c-axis.
14	345	Reeber, R. R.	1970	X	4.2-296		99.99 pure; specimen supplied by Fischer Chemical Co.; powder sample in clear-fused-silica capsule, purged and evacuated 3 times with chemically pure argon; sealing sample heat-treated at 1257 K for 14 hr and slow cooled to room temperature; lattice parameter expansion measured along a-axis; 3.2482 ± 0.00015 Å reported at 4.2 K; 3.2501Å at 293 K determined by graphical extrapolation.

SPECIFICATION TABLE 94. THERMAL LINEAR EXPANSION OF ZINC OXIDE ZnO (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
15	345	Reeber, R. R.	1970	X	4.2-296		The above specimen; lattice parameter expansion measured along c-axis; 5.2028 Å reported at 4.2 K; 5.2062 Å at 293 K determined by graphical interpolation.
16	653	Yates, B., Cooper, R. F., and Kreitman, M. M.	1971	X	90-260		Specimen obtained from Aerospace Research Lab, impurity level believed to be a few parts per million; linear thermal expansion coefficient perpendicular to c-axis measured in the "a-a" crystallographic plane.
17	653	Yates, B., et al.	1971	X	90-260		The above specimen except linear thermal expansion coefficient measured in the c crystallographic axis direction.
18	586	Valeev, Kh. S. and Kvaskov, V. B.	1973	L	473-1179		Specimen obtained by roasting for 1.5-2 hr in air pressed powders (Ar grade) at 1200-1250 C and sintered polycrystalline material; heating rate 2 deg/min; data from smoothed curve.

DATA TABLE 94. THERMAL LINEAR EXPANSION OF ZINC OXIDE ZnO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
309	0.01
473	0.11
673	0.25
873	0.41
1073	0.58
1273	0.76
1473	0.95

CURVE 2

T	$\Delta L/L_0$
309	0.00
473	0.09
673	0.20
873	0.30
1073	0.39
1273	0.48
1473	0.55

CURVE 3

T	$\Delta L/L_0$
373	0.05
673	0.23
973	0.45

CURVE 4‡

T	$\Delta L/L_0$
12	-0.046
13	-0.046*
15	-0.046*
20	-0.047*
22	-0.047
28	-0.047*
33	-0.047
38	-0.047*
43	-0.047
47	-0.047*
53	-0.048
60	-0.048*
63	-0.048
68	-0.048*
73	-0.049
78	-0.049*
78	-0.049*
83	-0.049
85	-0.049*

CURVE 4 (cont.)‡

T	$\Delta L/L_0$
95	-0.049
96	-0.049*
100	-0.049*
106	-0.049
116	-0.049
126	-0.048
137	-0.047
148	-0.046
157	-0.044
167	-0.043
179	-0.040
189	-0.038
198	-0.035*
215	-0.030
227	-0.026
234	-0.024
258	-0.015
275	-0.008*
293	0.000*
308	0.007*
321	0.013*

CURVE 5‡

T	$\Delta L/L_0$
9	-0.0190
12	-0.0190
13	-0.0190*
17	-0.0191*
23	-0.0192
27	-0.0193*
33	-0.0196
40	-0.0201
48	-0.0207
48	-0.0207
53	-0.0211*
53	-0.0211*
56	-0.0213
58	-0.0215
63	-0.0220
67	-0.0223*
75	-0.0230
82	-0.0236
87	-0.0240
95	-0.0246
95	-0.0246*

CURVE 5 (cont.)‡

T	$\Delta L/L_0$
105	-0.0252
115	-0.0256
115	-0.0256*
125	-0.0258
125	-0.0[illegible]*
127	-0.0258*
136	-0.0257
144	-0.0254
154	-0.0249
165	-0.0241
177	-0.0230
186	-0.0220
196	-0.0206
207	-0.0189
216	-0.0174
226	-0.0156
236	-0.0137
247	-0.0114
257	-0.0091
268	-0.0065
276	-0.0045
286	-0.0019
293	0.000*
297	0.001*
305	0.003*
317	0.007
327	0.010

CURVE 6

T	$\Delta L/L_0$
355	0.035
382	0.051
410	0.068
423	0.076
431	0.081
454	0.096
457	0.098*
466	0.104
484	0.117
491	0.122*
499	0.128*
518	0.141
530	0.150
537	0.155
555	0.168

CURVE 6 (cont.)

T	$\Delta L/L_0$
562	0.174*
576	0.184
596	0.200
612	0.213*
621	0.220*
637	0.232
667	0.256
675	0.263*
686	0.272
708	0.290
722	0.301
754	0.327

CURVE 7

T	$\Delta L/L_0$
357	0.023
373	0.028
388	0.034
400	0.038
406	0.041
413	0.043
428	0.049
439	0.054
446	0.057
457	0.061
477	0.070
484	0.073
494	0.077*
517	0.087
529	0.092
547	0.101
555	0.104
574	0.113
582	0.117
592	0.121
617	0.133
636	0.142
649	0.148
664	0.156
681	0.164
701	0.174
712	0.179
724	0.185
744	0.195
766	0.206

CURVE 7 (cont.)

T	$\Delta L/L_0$
779	0.212
787	0.216
804	0.225
821	0.233
832	0.239
841	0.243

CURVE 8

T	$\Delta L/L_0$
314	0.014
473	0.119
673	0.264
874	0.450
1074	0.619
1274	0.823

CURVE 9

T	$\Delta L/L_0$
314	0.008
473	0.072
673	0.172
874	0.262
1073	0.357
1273	0.430

CURVE 10

T	$\Delta L/L_0$
300	0.0061
401	0.0738
498	0.1292
523	0.1528
561	0.1692
612	0.2092
622	0.2184
693	0.2769
726	0.2861
772	0.3323
788	0.3507
816	0.3630
836	0.3754
892	0.4277

CURVE 11

T	$\Delta L/L_0$
300	0.0038*

CURVE 11 (cont.)

T	$\Delta L/L_0$
401	0.0576
498	0.0768
523	0.0787
561	0.1017
612	0.1190
622	0.1402
693	0.1843
726	0.1651
777	0.1901
788	0.2247
816	0.2112
926	0.2208
892	0.2611

CURVE 12

T	$\Delta L/L_0$
298	0.0033*
469	0.11

CURVE 13

T	$\Delta L/L_0$
298	0.0016*
469	0.056

CURVE 14

T	$\Delta L/L_0$
4	-0.0584
20	-0.0584
38	-0.0584
58	-0.0584
77	-0.0615
85	-0.0584
90	-0.0615
100	-0.0584
120	-0.0615
140	-0.0584
204	-0.0461
220	-0.0461
243	-0.0369
270	-0.0246
294	0.0000
296	-0.0030

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0 = 0$.

DATA TABLE 94. THERMAL LINEAR EXPANSION OF ZINC OXIDE ZnO (continued)

T	$\Delta L/L_0$
CURVE 15	
4.2	-0.0653
20	-0.0518
38	-0.0614
58	-0.0653
77	-0.0749
85	-0.0595*
90	-0.0403
100	-0.0614
120	-0.0326
140	-0.0403
204	-0.0345
220	-0.0441
243	-0.0422
270	0.0000
294	0.0000*
296	-0.0288
CURVE 16*,‡	
90	-0.054
100	-0.054
110	-0.054
120	-0.054
130	-0.053
140	-0.052
150	-0.051
160	-0.049
170	-0.047
180	-0.044
190	-0.042
200	-0.039
210	-0.035
220	-0.032
230	-0.028
240	-0.024
250	-0.019
260	-0.015
CURVE 17*,‡	
90	-0.025
100	-0.026
110	-0.027
120	-0.027
130	-0.027
140	-0.027
150	-0.026
160	-0.026

T	$\Delta L/L_0$
CURVE 17 (cont.)*,‡	
170	-0.025
180	-0.024
190	-0.023
200	-0.021
210	-0.020
220	-0.018
230	-0.016
240	-0.014
250	-0.011
260	-0.009
CURVE 18	
473	0.10
573	0.18
673	0.25*
773	0.33*
873	0.42
973	0.49
1073	0.56
1132	0.60
1179	0.61

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 94. COEFFICIENT OF THERMAL LINEAR EXPANSION OF ZINC OXIDE ZnO

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

CURVE 4‡

T	α
12	-0.01
13	-0.02*
15	-0.04
20	-0.10
22	-0.13
28	-0.22
33	-0.31
38	-0.37
43	-0.44
47	-0.50
53	-0.51
60	-0.50
63	-0.50
68	-0.49
73	-0.45
78	-0.41
78	-0.40*
83	-0.35
85	-0.31
95	-0.11
96	-0.10*
100	0.02
106	0.21
116	0.46
126	0.80
137	1.10
148	1.47
157	1.71
167	2.00
179	2.23
189	2.50
198	2.75
215	3.07
227	3.37
234	3.47
258	4.00
275	4.36
293	4.54
308	4.80*
321	4.99*

CURVE 5‡

T	α
9	-0.01
12	-0.03*
13	-0.05*
17	-0.10
23	-0.27
27	-0.38
33	-0.56
40	-0.72
48	-0.81
48	-0.82*
53	-0.86
53	-0.88*
56	-0.88
58	-0.87
63	-0.89
67	-0.87
75	-0.87
82	-0.85
87	-0.79
95	-0.76
95	-0.66
105	-0.50
115	-0.29
115	-0.28*
125	-0.04
125	-0.02*
127	0.02
136	0.22
144	0.37
154	0.63
165	0.83
177	1.06
186	1.26
196	1.43
207	1.60
216	1.75
226	1.89
236	2.01
247	2.17
257	2.32
268	2.44
276	2.57
286	2.72
293	2.77
297	2.84
305	2.95*
317	3.07*
327	3.15*

CURVE 6*,‡

T	α
355	5.63
382	5.85
410	6.26
423	6.26
431	6.42
454	6.81
457	6.68
466	6.85
484	7.26
491	7.12
499	7.05
518	7.25
530	7.41
537	7.33
555	7.50
562	7.59
576	7.69
596	7.90
612	7.92
621	7.85
637	8.00
667	7.97
675	8.11
686	8.17
708	8.17
722	8.14
754	8.24

CURVE 7*,‡

T	α
357	3.49
373	3.58
388	3.78
400	3.91
406	3.91
413	3.94
428	4.00
439	4.15
446	4.15
457	4.13
477	4.27
484	4.35
494	4.35
517	4.40
529	4.49
547	4.49

CURVE 7 (cont.)*,‡

T	α
555	4.62
574	4.69
582	4.66
592	4.59
617	4.73
636	4.79
649	4.81
664	4.86
681	4.90
701	4.90
712	4.91
724	4.94
744	4.95
766	4.96
779	5.08
787	4.96
804	4.99
821	4.99
832	4.92
841	5.07

CURVE 16‡

T	α
90	-0.20
100	0.00*
110	0.27
120	0.59
130	0.92
140	1.24
150	1.56
160	1.89
170	2.21
180	2.53
190	2.85
200	3.15
210	3.46
220	3.78
230	4.05
240	4.25
250	4.40
260	4.50

CURVE 17‡

T	α
90	-0.70
100	-0.55
110	-0.37
120	-0.16
130	0.06
140	0.29
150	0.51
160	0.74
170	0.95
180	1.15
190	1.34
200	1.51
210	1.70
220	1.88
230	2.06
240	2.24
250	2.40
260	2.56

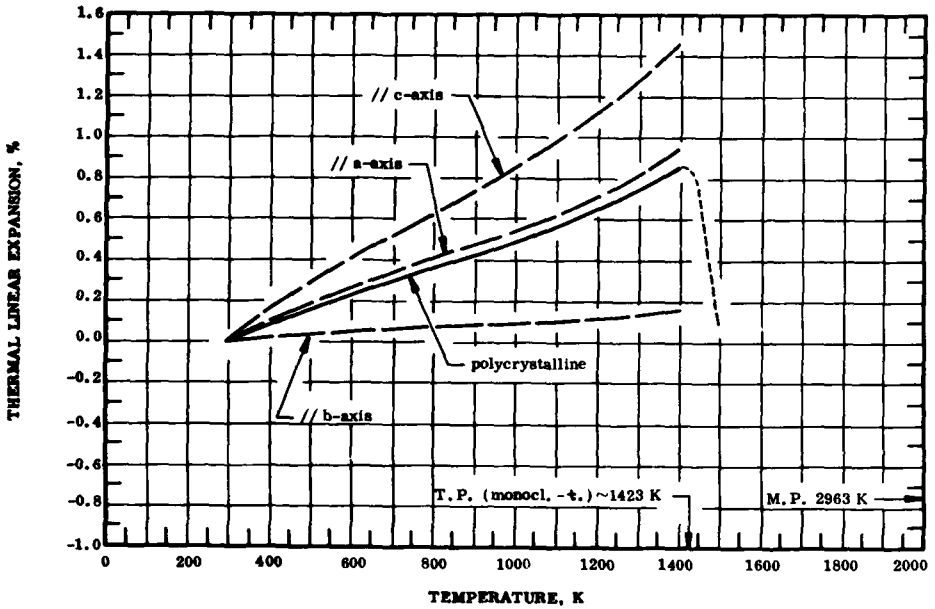
CURVE 17 (cont.)‡

T	α

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 95R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE ZrO_2



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Monoclinic Structure				
	// c-axis	// a-axis	// b-axis	polycrystalline	
T	$\Delta L/L_0$ †	$\Delta L/L_0$ †	$\Delta L/L_0$ †	$\Delta L/L_0$	α
293	0.000	0.000	0.000	0.000	8.8
400	0.150	0.100	0.020	0.088	7.6
500	0.280	0.180	0.031	0.158	7.1
600	0.400	0.258	0.042	0.229	6.7
700	0.513	0.332	0.052	0.293	6.5
800	0.621	0.400	0.063	0.360	6.4
900	0.731	0.465	0.075	0.421	6.4
1000	0.847	0.536	0.082	0.489	6.9
1100	0.970	0.610	0.100	0.560	7.5
1200	1.110	0.700	0.115	0.640	8.9
1300	1.270	0.810	0.141	0.738	10.5
1400	1.460	0.941	0.152	0.850	11.6

† Provisional values.

REMARKS

The recommended values for the polycrystalline sample are based on the data for the pure samples (curves 10, 31, 39 and 62). This result agrees well with the values calculated from the axial thermal expansion values. The provisional values for the axial values are based on data reported in curves 21 and 53 for //a-axis, curves 22 and 54 for //b-axis and curves 33 and 55 for //c-axis. These values are considered accurate to within ±5% for polycrystalline expansion and ±10% for axial expansion and are represented approximately by the following equations:

Monoclinic Structure

// c-axis: $\Delta L/L_0 = -0.560 + 2.336 \times 10^{-3} T - 1.654 \times 10^{-6} T^2 + 7.267 \times 10^{-10} T^3$

// a-axis: $\Delta L/L_0 = -0.401 + 1.721 \times 10^{-3} T - 1.383 \times 10^{-6} T^2 + 5.986 \times 10^{-10} T^3$

// b-axis: $\Delta L/L_0 = -0.488 + 2.036 \times 10^{-3} T - 1.482 \times 10^{-6} T^2 + 7.520 \times 10^{-11} T^3$

polycrystalline: $\Delta L/L_0 = -0.314 + 1.304 \times 10^{-3} T - 9.092 \times 10^{-7} T^2 + 4.084 \times 10^{-10} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

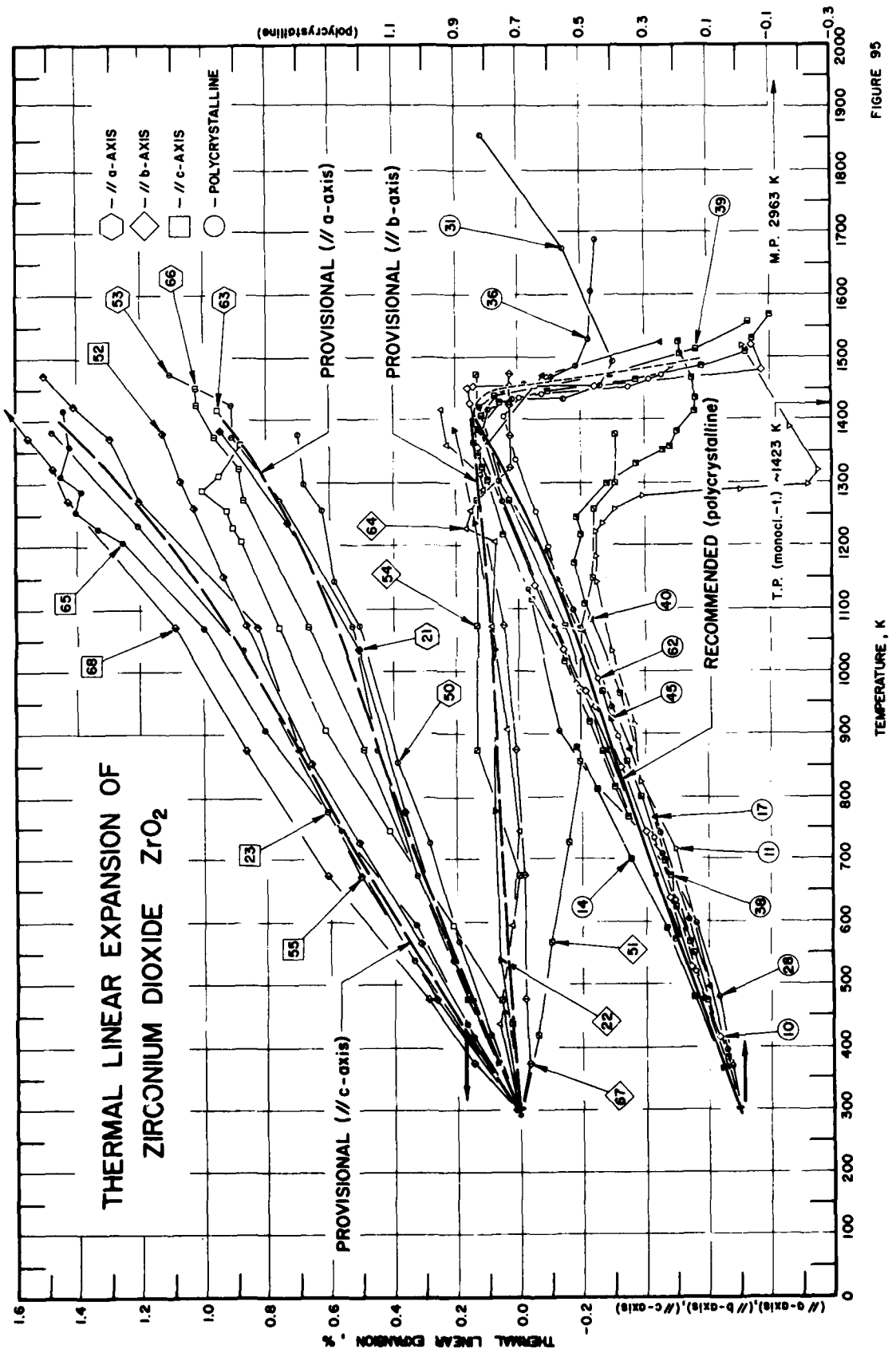

THERMAL LINEAR EXPANSION OF
ZIRCONIUM DIOXIDE ZrO_2
// a-AXIS
// b-AXIS
// c-AXIS
POLYCRYSTALLINE
PROVISIONAL (// a-axis)
PROVISIONAL (// b-axis)
PROVISIONAL (// c-axis)
RECOMMENDED (polycrystalline)
M.P. 2963 K
T.P. (monocl.→t.) ~1423 K
(polycrystalline)
THERMAL LINEAR EXPANSION , %
(// a-ax is), (// b-ax is), (// c-ax is)
TEMPERATURE , K

FIGURE 95

SPECIFICATION TABLE 95. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE ZrO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	231	Lang, S. M.	1964	X	1423-2273	TAM-HF	0.0125 Fe_2O_3, 0.0090 Al_2O_3, 0.0080 SiO_2, 0.0045 MgO, 0.0040 TiO_2, 0.0010 Cr_2O_3, 0.0010 others, hafnia-free specimen of tetragonal structure; obtained from National Lead Co.; lattice constant expansion measured along a-axis in air atmosphere with filtered CuKα radiation 3.639 Å reported at 1423.2 K; this curve is here reported using the first temperature (1423.2 K) as reference temperature at which $\Delta L/L_0 = 0$.
2*	231	Lang, S. M.	1964	X	1423-2273	TAM-HF	The above specimen; lattice constant expansion measured along c-axis; 5.274 Å reported at 1423.2 K; this curve is here reported using the first temperature (1423.2 K) as reference temperature at which $\Delta L/L_0 = 0$.
3*	231	Lang, S. M.	1964	X	1423-2273	WCR	0.0250 Fe_2O_3, 0.0100 Al_2O_3, 0.0050 SiO_2, 0.0025 each of MgO and TiO_2, 0.0010 Cr_2O_3, and 0.0010 others; reactor grade tetragonal, hafnia-free specimen; obtained from Wah Chang Corp; lattice constant expansion measured along a-axis in air atmosphere with filtered CuKα radiation; 3.640 Å reported at 1423.2 K; this curve is here reported using the first temperature (1423.2 K) as reference temperature at which $\Delta L/L_0 = 0$.
4*	231	Lang, S. M.	1964	X	1423-2273	WCR	The above specimen; lattice constant expansion measured along c-axis; 5.275 Å reported at 1423.2 K; this curve is here reported using the first temperature (1423.2 K) as reference temperature at which $\Delta L/L_0 = 0$.
5*	231	Lang, S. M.	1964	X	1423-2273	AHC	0.1100 SiO_2, 0.0400 Al_2O_3, 0.0240 Fe_2O_3, 0.0050 TiO_2, 0.0040 MgO, 0.0025 Cr_2O_3, and 0.0010 others; obtained from Zirconium Corp. of America; lattice constant expansion measured along a-axis; 3.639 Å reported at 1423.2 K; this curve is here reported using the first temperature (1423.2 K) as reference temperature at which $\Delta L/L_0 = 0$.
6*	231	Lang, S. M.	1964	X	1423-2273	AHC	The above specimen; lattice constant expansion measured along c-axis; 5.276 Å reported at 1423.2 K; this curve is here reported using the first temperature (1423.2 K) as reference temperature at which $\Delta L/L_0 = 0$.
7*	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	312-1771		100 pure; cubic specimen 0.5 x 0.5 x 7 in.; the ends sawed at rake and to point; fused; no significant change when cooling; data from smoothed curve; zero-point correction of 0.01% determined by graphica extrapolation.
8*	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	312-1771		Similar to the above specimen except coarse fused and stabilized; data from smoothed curve; zero-point correction of 0.01% determined by graphical extrapolation.
9*	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	1771-313		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.04% determined by graphical extrapolation.
10	232	Fehrenbacher, L.L. and Jacobson, L.A.	1965	L	301-1518		99.9 pure, spectrographic grade powder; rectangular bar specimen 0.375 x 2.25 in.; obtained from Wah Chang Corp; cold-pressed at 25 000 psi; sintered in tantalum resistance vacuum furnace at 2273 K for 20 hr, resulting in black, oxygen-deficient specimen of near theoretical density; monoclinic-tetragonal phase transformation at 1323-1423 K; heating rate 50 C per hr; zero-point correction of 0.01% determined by graphical extrapolation.
11	232	Fehrenbacher, L.L. and Jacobson, L.A.	1965	L	1518-304		The above specimen; expansion measured with decreasing temperature; zero-point correction of 0.04% determined by graphical extrapolation.

* Not shown in figure.

SPECIFICATION TABLE 95. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE ZrO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
12*	233	Leonov, A.I., Andreeva, A.B., and Keler, E.K.	1966	X	306-1379		99.3 pure specimen; synthesized in reducing atmosphere at 1923 K for 3 hr; zero-point correction of 0.04% determined by graphical extrapolation.
13*	69	Finlay, G.R.	1952		293, 1073		Stabilized; cubic structure specimen; m.p. 2873 K; density 5.78 g cm^{-3}.
14	145	Gangler, J.J.	1950	I	366-878		0.16 C added; three pyramids 4 to 5 mm high constituted a single specimen; stabilized; hot pressed; zero-point correction of 0.01% determined by graphical extrapolation.
15*	11	Austin, J.B.	1931	I	293-1223		97.69 ZrO_2, 1.00 Al_2O_3, 0.50 TiO_2, 0.25 Fe_2O_3, 0.24 SiO_2; calcined electrically-fused specimen; furnished by Titanium Alloy Manufacturing Co. of Niagara Falls, N.Y.; expansion measured parallel to axis of long basalt-like column.
16*	11	Austin, J.B.	1931	I	293-1123		The above specimen; expansion measured perpendicular to axis of column.
17	234	Geller, R.F. and Yavorsky, P.J.	1945	L	493-1522	Specimen B	98.0 ZrO_2, 1.21 SiO_2, 0.34 Al_2O_3, 0.17 CaO, 0.08 Fe_2O_3; specimen 325 mesh; fused; heat-treated at 2223 K; zero-point correction of 0.00% determined by graphical extrapolation.
18*	234	Geller, R.F. and Yavorsky, P.J.	1945	L	309-1502		Similar to the above specimen; heat-treated at 1688 K; zero-point correction of 0.00% determined by graphical extrapolation.
19*	234	Geller, R.F. and Yavorsky, P.J.	1945	L	347-1572	Specimen C	99.0 ZrO_2, 0.27 SiO_2, 0.24 CaO, 0.08 Al_2O_3, 0.02 Fe_2O_3; specimen calcined, heat-treated at 2223 K; zero-point correction of 0.02% determined by graphical extrapolation.
20*	234	Geller, R.F. and Yavorsky, P.J.	1945	L	347-1476		Similar to the above specimen; heat-treated at 1738 K; zero-point correction of 0.02% determined by graphical extrapolation.
21	61	Grain, C.F. and Campbell, W.J.	1962	X	300-1383	Baddeleyite	99.9 pure specimen; placed on alumina holder; fired at 1273 K for 24 hr; platinum powder used as internal standard; monoclinic structure at room temperature with four molecules per unit cell; cell parameter expansion measured along a-axis; 5.169 Å reported at room temperature; monoclinic to tetragonal transformation occurred at 1373 K; zero-point correction of 0.01% determined by graphical extrapolation.
22	61	Grain, C.F. and Campbell, W.J.	1962	X	300-1383	Baddeleyite	The above specimen; cell parameter expansion measured along b-axis of monoclinic phase; 5.232 Å reported at room temperature; zero-point correction of 0.00% determined by graphical extrapolation.
23	61	Grain, C.F. and Campbell, W.J.	1962	X	300-1383		The above specimen; cell parameter expansion measured along c-axis of monoclinic phase; 5.341 Å reported at room temperature; zero-point correction of 0.01% determined by graphical extrapolation.
24*	63	Pears, C.D.	1963	L	293-2722	Run No. E12	1.0 Ca, 0.1 Si, Mg, Ti, Al; specimen initial length 3.020 in., final length 2.942 in.; density at 198 K 5.36 g cm^{-3} before exposure, 5.35 g cm^{-3} after exposure; reported error 5%; data from smoothed curve.
25*	63	Pears, C.D.	1963	L	293-2755	Run No. E17	The above specimen; expansion measured on second test; reported error 5% data from smoothed curve.
26*	63	Pears, C.D.	1963	L	293-2758	Run No. E19	Similar to the above specimen; initial length 3.001 in., final length 2.956 in.; reported error 5%; data from smoothed curve.
27*	22	Sklarew, S.	1959		294, 1697	Rokide Z	98 pure; rod specimen 0.125 to 0.125 to 0.1875 in. diameter; molten droplets sprayed on working surface; expansion of coating measured.

* Not shown in figure.

SPECIFICATION TABLE 95. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE ZrO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
28	346	Leonard, B.G., Leggett, H., and Edlin, V.	1966		370-1130		Chemically bonded, cubic specimen.
29*	346	Leonard, B.G., et al.	1966		486-1082		Sintered, cubic specimen.
30*	346	Leonard, B.G., et al.	1966		483-1102		Sintered mixture of cubic and monoclinic crystals specimen.
31	235	Burdick, R.B., Hoskyns, W.R., Smith, C.F., and Crandall, W.B.	1964	L	368-1857	TAM	Special hydrous specimen; monoclinic structure; 0.25 in. square, 0.75 in. long; fabricated by cold-pressing, vacuum sintering; calcined at 811 K, then reduced to powder; heat-treated at 1173 K for 14-18 hr; heating rate 3 C per min; data from smoothed curve; zero-point correction of 0.02% determined by graphical extrapolation.
32*	235	Burdick, R.B., et al.	1964	L	1857-301	TAM	The above specimen; expansion measured with decreasing temperature; cooling rate 3 C per min; zero-point correction of -0.84% determined by graphical extrapolation.
33*	236	Karaukov, A.G., Grebenyuk, A.A., and Rudyak, I.N.	1967	L	1405-2532		Specimen containing 18% of monoclinic phase; this curve is here reported using the first temperature (1405 K) as reference temperature at which $\Delta L/L_0 = 0$, due to insufficient information regarding the phase changes.
34*	236	Karaukov, A.G., et al.	1967	L	1346-2460		Specimen containing 36% of monoclinic phase; this curve is here reported using the first given temperature (1346 K) as reference temperature at which $\Delta L/L_0 = 0$.
35*	236	Karaukov, A.G., et al.	1967	L	1410-2554		Specimen containing 48% of monoclinic phase; this curve is here reported using the first temperature (1410 K) as reference temperature at which $\Delta L/L_0 = 0$.
36	41	Burdick, R.B. and Hoskyns, W.R.	1963	L	395-1688	TAM E. F.	Specimen 0.375 in. square, 0.75 in. long; hot-pressed, heat-treated at 1373 K for 6 hr before final grinding; heating rate 2.5 C per min; zero-point correction of 0.02% determined by graphical extrapolation.
37*	41	Burdick, R.B. and Hoskyns, W.R.	1963	L	1688-318		The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.54% determined by graphical extrapolation.
38	72	Fulkerson, S.D.	1960	L	473-1568		Hafnium-free, polycrystalline specimen; inversion of monoclinic to tetragonal crystal form observed between 1373 and 1473 K.
39	113	Curtis, C.E., Doney, L.M., and Johnson, J.R.	1954	L	361-1558	Specimen A	0.06 Fe, 0.02 Si, 0.015 Al, 0.008 Hf, 0.006 Ti; monoclinic structure; specimen 0.375 in. diameter, 1 in. long; prepared by dry-pressing and firing at 1873 K for 2 hr; m.p. 3123 K; heating rate 3 C per min; data from smoothed curve.
40	237	Pulliam, G.R.	1959	L	299-1523		Zr-stabilized, fused polycrystalline specimen; obtained from WADC Aeronautical Research Lab; prepared by sintering ZrO_2 with 15% Zr; showed highly oriented grain structure; single phased with metal inclusions; phase transition initiated at about 1223 K and computed at about 1423 K; expansion of specimen length measured; 1.9628 in. reported at 299 K; 1.9627 in. at 293 K determined by graphical extrapolation.
41*	238	Curtis, C.E.	1947	L	611-1474		99.0 pure; specimen pressed, calcined at 2200 K; heating rate 192 C per min; expansion data reported without specified reference temperature.
42*	238	Curtis, C.E.	1947	L	302-1507		97.0 pure specimen; cast; heating rate 192 C per min.

*Not shown in figure.

SPECIFICATION TABLE 95. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE ZrO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
43*	84	Levenstein, M.A.	1961	L	297-1366		Tube specimen of cubic and at least 5% monoclinic structures; 0.035 in. thick; 2.560 in. long; fabricated by plasma spraying a layer onto a rotating aluminum tube of 0.125 in. diameter; reported error 2%.
44*	28	Merritt, G.E.	1926	I	552-1164		Pure specimen; fused; obtained from Welsbach Co.
45	28	Merritt, G.E.	1926	I	396-969		Pure specimen; obtained from Welsbach Co.; fused without formation of carbide; ground and sintered with organic binder at 2023 K; expansion measured on first test; zero-point correction of 0.01% determined by graphical extrapolation.
46*	28	Merritt, G.E.	1926	I	453-1160		The above specimen; expansion measured on second test; zero-point correction of 0.01% determined by graphical extrapolation.
47*	28	Merritt, G.E.	1926	I	385-1084		Crystalline specimen; expansion measured parallel to long axis; zero-point correction of 0.01% determined by graphical extrapolation.
48*	28	Merritt, G.E.	1926	I	466-1001		The above specimen; expansion measured perpendicular to long axis; zero-point correction of 0.01% determined by graphical extrapolation.
49*	28	Merritt, G.E.	1926	I	434-972		Similar to the above specimen; ground and sintered with sugar; zero-point correction of 0.01% determined by graphical extrapolation.
50	239	Filatov, S.K., Frank-Kamenetskii, V.A., and Zhuravina, T.A.	1969	X	293-1376		95.0 ZrO_2, 1.8 HfO_2, 1.3 TiO_2, 0.8 Fe_2O_3, 0.6 SiO_2, 0.4 CaO, 0.1 MgO; powder fused in arc furnace, fired in air at 1273 K for several hr; parameter expansion measured along a-axis of monoclinic cell; 5.138 Å reported at 293 K.
51	239	Filatov, S.K., et al.	1969	X	293-1376		The above specimen; parameter expansion measured along b-axis of monoclinic cell; 5.204 Å reported at 293 K.
52	239	Filatov, S.K., et al.	1969	X	293-1380		The above specimen; parameter expansion measured along c-axis of monoclinic cell; 5.313 Å reported at 293 K.
53	240	Kubo, T., Kato, M., and Kohatsu, I.	1966	X	298-1473		0.03 each of Bi, Hf, 0.002 Ca, 0.003 each of Al, Fe, <0.001 of Mg, Th, Cu, Ti, Ag, Pb, B; specimen obtained from Japan; monoclinic phase converted to tetragonal phase at 1273-1473 K; lattice constant expansion measured along a-axis of monoclinic phase; 5.142 Å reported at 298.2 K; 5.141 Å at 293.2 K determined by graphical extrapolation.
54	240	Kubo, T., et al.	1966	X	298-1473		The above specimen; lattice constant expansion measured along b-axis of monoclinic phase; 5.202 Å reported at 298.2 K; 5.202 Å at 293.2 K determined by graphical extrapolation.
55	240	Kubo, T., et al.	1966	X	298-1473		The above specimen; lattice constant expansion measured along c-axis of monoclinic phase; 5.312 Å reported at 298.2 K; 5.311 Å at 293.2 K determined by graphical extrapolation.
56*	240	Kubo, T., et al.	1966	X	1303-1823		Similar to the above specimen; lattice constant expansion measured along a-axis of tetragonal phase; only data on lattice constant reported.
57*	240	Kubo, T., et al.	1966	X	1303-1823		The above specimen; lattice constant expansion measured along c-axis of tetragonal phase; only data on lattice constant reported.
58*	241	Thielke, N.R.	1954	L	273-1473		Powdered specimen; 1 x 1 x 10 cm block; sintered at 1273 K for 3 hr; zero-point correction of -0.012%.
59*	241	Thielke, N.R.	1954	L	273-1610		Similar to the above specimen; sintered at 1423 K for 3 hr; zero-point correction of -0.012%.

* Not shown in figure.

SPECIFICATION TABLE 95. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE ZrO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
60*	241	Thielke, N.R.	1954	L	273-1487		Similar to the above specimen; 0.5 SiO_2 added; sintered at 1273 K for 3 hr; zero-point correction of -0.003%.
61*	241	Thielke, N.R.	1954	L	273-1604		Similar to the above specimen; sintered at 1423 K for 3 hr; zero-point correction of -0.003%.
62	654	Stewart, R.K. and Hunter, O., Jr.	1970	L	293-1486		ZrO_2 sample from two sources, one lot contained 0.49% impurities plus 0.045% Hf with average particle size ≈ 1 μm; the other contained 0.14% impurities plus 1.5% Hf with average particle size ≈ 0.44 μm; powders mixed with water, dried, formed into bars, and isostatically pressed at 50,000 psi; specimens fired at 2000 C for 2 hr, heated in air at 1250 C for 12 hr, and cooled to room temperature at 40-70 C/hr; zero-point correction 0.023%.
63	598	Patil, R.N. and Subbarao, E.C.	1969	X	306-1666		99.9 pure specimen obtained from Atomic Energy Establishment, Trombay, India; spectrochemical analysis: Al, 45 ppm; Fe, 150 ppm; Mg, 275 ppm; Pb, 500 ppm; Si, 1000 ppm; Ti, 150 ppm; and Hf, 0.02%; transition temperature of monoclinic to tetragonal phase at 1417 K; lattice parameter measured along a-axis; 5.1415 Å reported at 306 K for monoclinic phase.
64	598	Patil, R.N. and Subbarao, E.C.	1969	X	306-1417		The above specimen except lattice parameter measured along b-axis of monoclinic phase; 5.2056 Å reported at 306 K.
65	598	Patil, R.N. and Subbarao, E.C.	1969	X	306-1666		The above specimen except lattice parameter measured along c-axis; 5.3128 Å reported at 306 K for monoclinic phase.
66	600	Filatov, S.K. and Frank-Kamenetskii, V.A.	1969	X	293-1473		99.7 pure measured in air; CuKα radiation and nickel filter used; anisotropy $\alpha_c > \alpha_a$ increased in the region of monoclinic-tetragonal transformation (1423-1523 K) where $\alpha_b \sim 0$ and $\alpha_c \sim$ volume expansion coefficient, the angle between α_c and (001) increasing from 29 to 45 degree; phase transformation is accompanied by a structural contraction of 3.42%; lattice parameter of a-axis of monoclinic structure measured; 5.1428 Å reported at 293 K.
67	600	Filatov, S.K. and Frank-Kamenetskii, V.A.	1969	X	293-1473		The above specimen; lattice parameter of b-axis of monoclinic structure measured; 5.2113 Å reported at 293 K.
68	600	Filatov, S.K. and Frank-Kamenetskii, V.A.	1969	X	293-1473		The above specimen; lattice parameter of c-axis of monoclinic structure measured; 5.3072 Å reported at 293 K.

* Not shown in figure.

DATA TABLE 95. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE ZrO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*,†	
1423	0.000
1473	0.082
1523	0.137
1573	0.192
1623	0.274
1673	0.329
1723	0.384
1773	0.467
1823	0.522
1873	0.604
1923	0.659
1973	0.714
2023	0.796
2073	0.851
2123	0.906
2173	0.989
2223	1.044
2273	1.099
CURVE 2*,†	
1423	0.000
1473	0.075
1523	0.151
1573	0.227
1623	0.303
1673	0.379
1723	0.455
1773	0.530
1823	0.606
1873	0.682
1923	0.758
1973	0.834
2023	0.910
2073	0.967
2123	1.042
2173	1.118
2223	1.194
2273	1.270
CURVE 3*,†	
1423	0.000
1473	0.054
1523	0.109
1573	0.164

T	$\Delta L/L_0$
CURVE 3 (cont.)*,†	
1623	0.247
1673	0.302
1723	0.357
1773	0.412
1823	0.494
1873	0.549
1923	0.604
1973	0.659
2023	0.714
2073	0.796
2123	0.851
2173	0.906
2223	0.961
2273	1.043
CURVE 4*,†	
1423	0.000
1473	0.056
1523	0.132
1573	0.208
1623	0.284
1673	0.360
1723	0.417
1773	0.492
1823	0.568
1873	0.644
1923	0.720
1973	0.777
2023	0.853
2073	0.928
2123	1.004
2173	1.080
2223	1.137
2273	1.213
CURVE 5*,†	
1423	0.000
1473	0.082
1523	0.137
1573	0.192
1623	0.247
1673	0.302
1723	0.357
1773	0.439

T	$\Delta L/L_0$
CURVE 5 (cont.)*,†	
1823	0.494
1873	0.549
1923	0.604
1973	0.659
2023	0.714
2073	0.796
2123	0.851
2173	0.906
2223	0.961
2273	1.061
CURVE 6*,†	
1423	0.000
1473	0.056
1523	0.132
1573	0.189
1623	0.265
1673	0.341
1723	0.398
1773	0.473
1823	0.549
1873	0.606
1923	0.682
1973	0.739
2023	0.815
2073	0.890
2123	0.947
2173	1.023
2223	1.099
2273	1.156
CURVE 7*	
312	0.01
426	0.10
571	0.22
687	0.33
832	0.48
968	0.64
1120	0.83
1283	1.03
1431	1.24
1579	1.45
1771	1.74

T	$\Delta L/L_0$
CURVE 8*	
312	0.01
446	0.10
581	0.18
679	0.26
806	0.38
940	0.49
1063	0.56
1172	0.62
1299	0.63
1365	0.63
1415	0.63
1446	0.65
1503	0.72
1584	0.83
1673	0.97
1771	1.13
CURVE 9*	
1771	1.08
1418	0.60
1287	0.43
1213	0.33
1259	0.29
1132	0.30
1087	0.33
899	0.24
709	0.16
587	0.12
466	0.05
313	0.01
CURVE 10	
301	0.01
414	0.07
527	0.16
639	0.23
743	0.30
846	0.38
941	0.46
967	0.49
978	0.52
1033	0.56
1139	0.65
1357	0.83

T	$\Delta L/L_0$
CURVE 10 (cont.)	
1383	0.84
1425	0.85
1450	0.86
1453	0.84
1453	0.46
1480	-0.07
1518	-0.04
CURVE 11	
1518	-0.01
1479	-0.07*
1389	-0.16
1318	-0.25
1294	-0.22
1287	0.00
1276	0.31
1259	0.40
1234	0.44
1220	0.46
1183	0.46
1143	0.46
1032	0.41
915	0.34
882	0.32
714	0.21
304	0.01*
CURVE 12*	
306	0.01
374	0.06
479	0.14
578	0.22
680	0.30
776	0.37
880	0.44
980	0.52
1080	0.60
1179	0.68
1281	0.75
1379	0.82
CURVE 13*	
1073	0.55

T	$\Delta L/L_0$
CURVE 14	
366	0.06
478	0.15
588	0.24
699	0.35
811	0.46
878	0.52
CURVE 15*	
293	0.000
323	0.015
373	0.040
423	0.065
473	0.095
523	0.120
573	0.150
623	0.178
673	0.205
723	0.238
773	0.270
823	0.295
873	0.321
923	0.353
973	0.380
1023	0.410
1073	0.470
1173	0.500
1223	0.530
CURVE 16*	
293	0.000*
323	0.025
373	0.058*
423	0.093
473	0.133
523	0.173
573	0.220*
623	0.260
673	0.308
723	0.355
773	0.400
823	0.440
873	0.487
923	0.531
973	0.571

*Not shown in figure.

†This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 95. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE ZrO_2 (continued)

T	$\Delta L/L_0$
CURVE 16 (cont.)*	
1023	0.620
1073	0.675
1123	0.730
CURVE 17	
493	0.101
769	0.274
875	0.351
1067	0.500
1192	0.623
1362	0.792
1472	0.622
1522	0.257
CURVE 18*	
309	0.00
466	0.12
669	0.25
869	0.39
1068	0.56
1269	0.74
1450	0.67
1502	0.04
CURVE 19*	
347	0.03
476	0.12
674	0.26
871	0.40
1076	0.55
1173	0.64
1268	0.72
1316	0.70
1371	0.69
1477	0.62
1512	0.03
CURVE 20*	
347	0.03
482	0.12
673	0.26
873	0.41
1075	0.58

T	$\Delta L/L_0$
CURVE 20 (cont.)*	
1274	0.77
1321	0.78
1382	0.79
1431	0.78
1476	0.56
CURVE 21	
300	0.01
537	0.21
777	0.37
1032	0.51
1237	0.74
1383	0.95
CURVE 22	
300	0.00
537	0.06
777	0.08
1032	0.08
1237	0.14
1383	0.20
CURVE 23	
300	0.01*
537	0.34
777	0.61
1032	0.88
1237	1.21
1383	1.48
CURVE 24*	
293	0.000
525	0.180
759	0.400
1072	0.610
1105	0.620
1310	0.760
1649	1.100
1910	1.350
2188	1.590
2435	1.700
2435	1.680
2544	1.740

T	$\Delta L/L_0$
CURVE 24 (cont.)*	
2588	1.170
2722	0.990
2722	0.570
2722	0.090
CURVE 25*	
294	0.000
540	0.240
813	0.500
1086	0.790
1116	0.810
1547	1.430
1655	1.580
1908	1.800
2233	2.110
2460	2.340
2611	2.440
2727	2.890
2755	1.850
CURVE 26*	
294	0.000
519	0.170
734	0.340
944	0.470
1100	0.560
1097	0.560
1310	0.660
1594	0.900
1891	1.160
2216	1.280
2460	1.110
2669	1.010
2758	0.630
CURVE 27*	
294	0.00
1672	1.58
CURVE 28	
370	0.032
476	0.074
597	0.145

T	$\Delta L/L_0$
CURVE 28 (cont.)	
708	0.251
811	0.464*
904	0.575
1130	0.679
CURVE 29*	
486	0.185
598	0.308
683	0.384
876	0.533
1082	0.730
CURVE 30*	
483	0.131
677	0.306
916	0.494
1102	0.608
CURVE 31	
368	0.05
473	0.12
673	0.27
873	0.42
1073	0.59
1273	0.75
1381	0.82*
1416	0.80
1433	0.72
1433	0.56
1454	0.45
1494	0.40
1673	0.56
1857	0.82
CURVE 32*	
1857	-0.04
1673	-0.33
1473	-0.61
1284	-0.82
1273	-0.69
1230	0.20
1173	0.38
1073	0.43

T	$\Delta L/L_0$
CURVE 32 (cont.)*	
873	0.35
673	0.22
473	0.10
301	0.00
CURVE 33*, †	
1405	0.00
1528	0.16
1625	0.27
1799	0.53
1937	0.76
2024	0.97
2164	1.19
2258	1.25
2315	1.34
2357	1.44
2485	1.55
2532	1.58
CURVE 34*, †	
1346	0.00
1443	0.03
1663	0.28
1791	0.45
1953	0.69
2030	0.83
2135	1.01
2460	1.70
CURVE 35*, †	
1410	0.00
1465	0.04
1574	0.06
1657	-0.24
1709	-0.27
1759	-0.24
1845	-0.04
2027	0.23
2173	0.46
2278	0.66
2484	1.17
2554	1.41

T	$\Delta L/L_0$
CURVE 36	
395	0.05
604	0.17
742	0.26
943	0.41
1098	0.53
1149	0.58
1301	0.76
1420	0.83
1447	0.75
1459	0.68
1470	0.60
1486	0.52
1529	0.48
1605	0.47
1688	0.46
CURVE 37*	
1699	-0.11
1553	-0.28
1420	-0.41
1261	-0.61
1254	-0.53
1250	-0.45
1241	-0.28
1239	-0.10
1234	0.14
1186	0.37
1173	0.45
1126	0.49
1060	0.48
964	0.42
743	0.28
539	0.16
480	0.12
418	0.08
318	0.03
CURVE 38	
473	0.14
570	0.21
673	0.28
769	0.36
815	0.40
918	0.48
1015	0.56

*Not shown in figure.

†This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 95. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE ZrO_2 (continued)

T	$\Delta L/L_0$
CURVE 38 (cont.)	
1115	0.66
1217	0.75
1304	0.80
1324	0.82
1343	0.83
1364	0.84
1384	0.83
1427	0.76
1448	0.61
1465	0.33
1486	0.12
1507	-0.02
1528	-0.04
1568	-0.10
CURVE 39	
361	0.06*
473	0.15*
673	0.29*
873	0.44
1073	0.59
1273	0.73
1376	0.81*
1406	0.82
1439	0.79
1473	0.41
1511	0.14
1558	-0.03
CURVE 40	
299	0.0030*
383	0.0468
477	0.1059*
568	0.1635
695	0.2476
766	0.2802*
873	0.3479
964	0.3836
1081	0.4758
1108	0.4921
1171	0.5288
1246	0.5201
1218	0.5099
1299	0.4228
1330	0.3275
1352	0.2460
1358	0.2256
1380	0.2053
1411	0.1457
1434	0.1421
1469	0.1553
1504	0.1930
1523	0.1951
CURVE 41*	
611	0.03
734	0.14
817	0.24
956	0.32
994	0.38
1005	0.41
1078	0.43
1147	0.49
1180	0.58
1274	0.62
1337	0.62
1419	0.62
1432	0.52
1432	0.42
1440	0.31
1463	0.09
1474	-0.07
CURVE 42*	
302	0.01
338	0.04
444	0.09
513	0.15
577	0.18
656	0.23
708	0.27
758	0.32
809	0.36
879	0.40
916	0.45
977	0.49
1032	0.52
1114	0.59
1214	0.68
1258	0.70
1322	0.77
1357	0.78
1430	0.80
1436	0.78
1450	0.67
1484	0.51
1507	0.43
CURVE 43*	
297	0.002
478	0.089
589	0.143
700	0.213
811	0.291
922	0.383
1033	0.464
1145	0.539
1251	0.609
1366	0.669
CURVE 44*	
552	0.15
698	0.23
829	0.31
977	0.41
1114	0.50
1164	0.53
CURVE 45	
396	0.06*
473	0.11*
550	0.15
623	0.21
690	0.25*
800	0.32
857	0.36
923	0.41
969	0.44
CURVE 46*	
453	0.09
653	0.21
828	0.32
973	0.42
1045	0.47
1115	0.51
1160	0.54
CURVE 47*	
385	0.07
542	0.19
664	0.29
800	0.41
931	0.52
1084	0.65
CURVE 48*	
466	0.12
639	0.25
753	0.33
836	0.39
920	0.45
1001	0.51
CURVE 49*	
434	0.09
507	0.14
590	0.18
653	0.23
759	0.30
835	0.36
913	0.41
972	0.45
CURVE 50	
293	0.000
417	0.097
568	0.195
726	0.292
854	0.389
1073	0.506
1145	0.584
1259	0.623
1299	0.681
1376	0.701
CURVE 51	
293	0.000*
419	-0.058
565	-0.096
725	-0.154
856	-0.192
1069	-0.192
1150	-0.231
1260	-0.231
1297	-0.307
1376	-0.307
CURVE 52	
293	0.000*
416	0.151
564	0.320
726	0.508
852	0.659
1078	0.866
1154	0.941
1261	1.035
1303	1.073
1380	1.129
CURVE 53	
298	0.019*
473	0.156
673	0.331
873	0.447
1073	0.525
1273	0.759
1373	0.914
1423	0.914
1473	1.109
CURVE 54	
298	0.000*
473	0.058
673	0.000
873	0.134
1073	0.134
1273	0.134
1373	0.134*
1423	0.134*
1473	0.134
CURVE 55	
298	0.019*
473	0.264
673	0.508
873	0.697
1073	0.828
1273	1.205
1373	1.299
1423	1.412
1473	1.506

T	a (Å)
CURVE 56*	
1303	3.632
1423	3.636
1543	3.640
1673	3.646
1823	3.651

T	c (Å)
CURVE 57*	
1303	5.263
1423	5.265
1543	5.276
1673	5.283
1823	5.294

T	$\Delta L/L_0$
CURVE 58*	
273	-0.012
293	0.000
473	0.097
673	0.229
873	0.339
1073	0.468
1273	0.568
1332	0.610
1473	-2.512

*Not shown in figure.

†This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 95. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE ZrO_2 (continued)

T	$\Delta L/L_0$
CURVE 59*	
273	-0.012
293	0.000
473	0.097
673	0.229
873	0.339
1073	0.468
1273	0.568
1332	0.610
1473	-0.233
1610	-1.012
CURVE 60*	
273	-0.003
293	0.000
473	0.094
673	0.222
873	0.340
1073	0.451
1224	0.550
1273	0.533
1304	0.495
1360	0.357
1390	0.226
1473	-2.520
1487	-3.000
CURVE 61*	
273	-0.003
293	0.000
473	0.094
673	0.222
873	0.340
1073	0.451
1262	0.556
1273	0.556
1338	0.534
1378	0.472
1405	0.395
1473	-0.290
1604	-1.539

T	$\Delta L/L_0$
CURVE 62	
293	0.000*
519	0.149
636	0.215
705	0.258*
732	0.279
894	0.393
988	0.454
1068	0.513*
1129	0.568
1197	0.609
1255	0.644
1336	0.709
1404	0.742
1435	0.698
1441	0.627
1452	0.356
1467	0.286
1471	0.249
1486	0.220
CURVE 63	
306	0.001* monocl.
436	0.024
592	0.213
748	0.417
906	0.616
1071	0.761
1205	0.880
1229	0.910
1258	0.930
1287	1.003
1313	0.955
1362	0.882
1417	0.960
T	a(Å)
1425	3.6429* t.
1510	3.6474*
1587	3.6501*
1666	3.6526*
T	$\Delta L/L_0$
CURVE 64	
306	0.001*
436	0.062

T	$\Delta L/L_0$
CURVE 64 (cont.)	
592	0.021
748	0.000
906	0.039
1071	0.090
1205	0.073
1229	0.166
1258	0.154
1287	0.116
1313	0.123
1362	0.225
1417	0.246
CURVE 65	
306	0.001* monocl.
436	0.170
592	0.334
748	0.566
906	0.808
1071	1.001
1205	1.259
1229	1.334
1258	1.402
1287	1.382
1313	1.451
1362	1.423
1417	1.441
T	c(Å)
1425	5.2724* t.
1510	5.2784*
1587	5.2863*
1666	5.2928*
CURVE 66	
293	0.0000*
373	0.0700
473	0.1633
673	0.3344*
873	0.4919
1073	0.6650
1273	0.8770
1323	0.8925
1373	0.9645
1423	1.0247

T	$\Delta L/L_0$
CURVE 66 (cont.)	
1453	1.0247
1473	1.1122*
CURVE 67	
293	0.0000*
373	-0.0288
473	-0.0173
673	-0.0173
873	0.0096
1073	0.0461
1273	0.0307*
1323	0.0269
1373	0.0269
1423	0.0269
1453	0.0269
1473	0.0269
CURVE 68	
293	0.0000*
373	0.1489
473	0.2996
673	0.6105
873	0.8649
1073	1.0910
1273	1.4245
1323	1.4754
1373	1.5564
1423	1.6412*
1453	1.7147*
1473	1.7486*

*Not shown in figure.

3. COMPLEX OXIDES

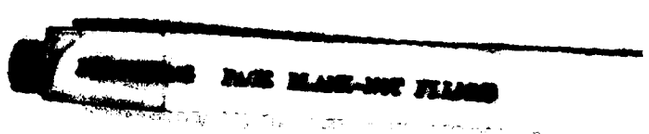
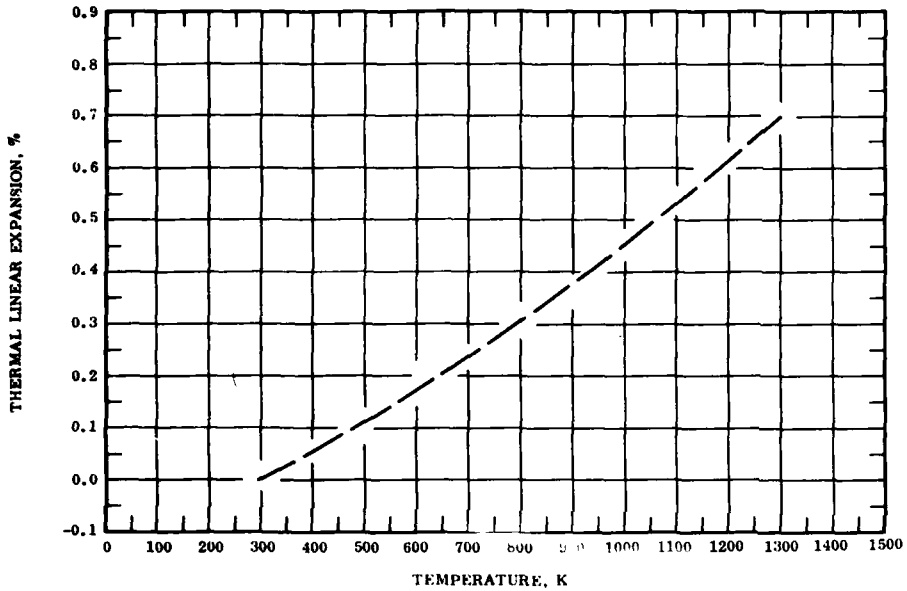


FIGURE AND TABLE NO. 96R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $CaO \cdot Al_2O_3$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, $10^{-6}\,K^{-1}$]

T	$\Delta L/L_0$	α
293	0.000	4.7
400	0.055	5.3
500	0.110	5.9
600	0.171	6.4
700	0.236	6.8
800	0.306	7.2
900	0.380	7.5
1000	0.457	7.8
1100	0.536	8.0
1200	0.618	8.2
1300	0.700	8.3

REMARKS

The provisional values are based on the data for the pure sample and are considered accurate to within ±7%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.107 + 2.578 \times 10^{-4}\,T + 3.968 \times 10^{-7}\,T^2 - 9.077 \times 10^{-11}\,T^3$$

The tabulated values for the coefficient of thermal expansion are based primarily on the experimental data and are considered accurate to about ±10%.

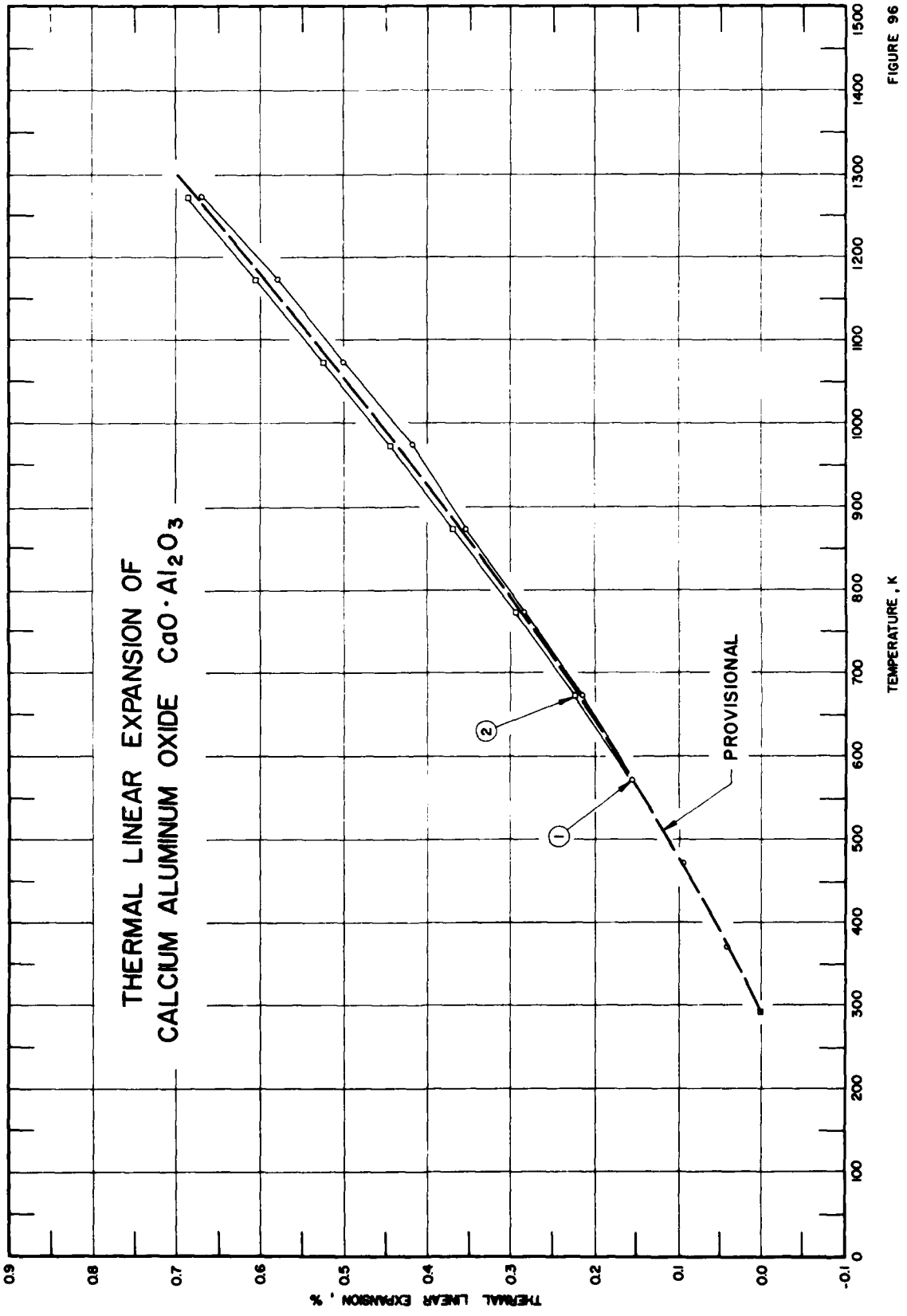

THERMAL LINEAR EXPANSION OF
CALCIUM ALUMINUM OXIDE CaO·Al2O3
PROVISIONAL
1
2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 96

SPECIFICATION TABLE 96. THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $CaO \cdot Al_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	122	Rigby, G.R. and Green, A.T.	1943	L	373-1473	Artificial mineral	Specimen prepared from lime and alumina; heated at 1473 K for 8 hr; powdered and reheated at 1623-1673 K for 2 hr; three heat treatments at this temperature; zero-point correction of 0.042% determined by graphical extrapolation.
2	669	Yanishevskii, V.M., Popova, E.I., and Kuryleva, V.F.	1969	L	373-1273		No details given; data reported by Kantsliz, E. and Ambruz, V. Rzhkhimiya, Summary Vol. No. 9 (1965) cited by authors.

DATA TABLE 96. THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $CaO \cdot Al_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2	
373	0.042	293	0.000
473	0.095	373	0.040
573	0.155	473	0.097
673	0.213	573	0.158
773	0.285	673	0.225
873	0.354	773	0.295
973	0.419	873	0.370
1073	0.500	973	0.447
1173	0.580	1073	0.526
1273	0.670	1173	0.606
1373	0.713	1273	0.688
1473	0.793		

DATA TABLE 96. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $CaO \cdot Al_2O_3$

[Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\ K^{-1}$]

T	α
CURVE 2*	
293	4.81
373	5.31
473	5.93
573	6.39
673	6.87
773	7.31
873	7.60
973	7.82
1073	7.96
1173	8.11
1273	8.24

* Not shown in figure.

SPECIFICATION TABLE 97. THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $CaO \cdot 6Al_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	18	Floyd, J.R.	1964	L	298-1273	Calcium hexaluminate $CaO \cdot 6Al_2O_3$	Specimen prepared from calcined alumina and $CaCO_3$; wet-milled in 3000 g batches for 24 hr with 4500 g of 1 in. diameter alumina balls in 5.5 qt. alumina mill, dried to 473 K, formed into pressing granules using organic binder, dry pressed, fired to 1923 K at average heating of 373 K per hr, soaked for 3 hr, and cooled at average rate of 373 K per hr.

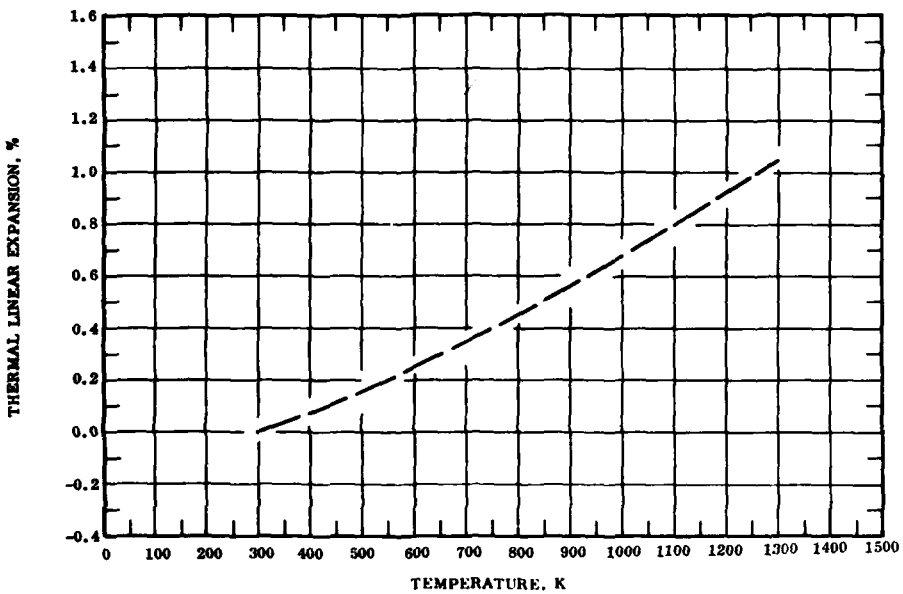
DATA TABLE 97. THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $CaO \cdot 6Al_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
298	0.005
373	0.039
473	0.107
573	0.193
673	0.279
773	0.369
873	0.459
973	0.553
1073	0.653
1173	0.755
1273	0.871

* No figure given.

FIGURE AND TABLE NO. 98R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $3CaO \cdot Al_2O_3$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, $10^{-6}\ K^{-1}$]

T	$\Delta L/L_0$	α
293	0.000	6.8
400	0.079	7.9
500	0.162	8.6
600	0.252	9.3
700	0.348	10.0
800	0.451	10.6
900	0.560	11.1
1000	0.673	11.6
1100	0.791	12.0
1200	0.913	12.4
1300	1.038	12.5

REMARKS

The provisional values are based on the data for the pure samples and are considered accurate to within ±7%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.164 + 4.180 \times 10^{-4}\ T + 5.193 \times 10^{-7}\ T^2 - 9.919 \times 10^{-11}\ T^3$$

The tabulated values for the coefficient of thermal expansion are based primarily on the experimental data and are considered accurate to about ±10%.

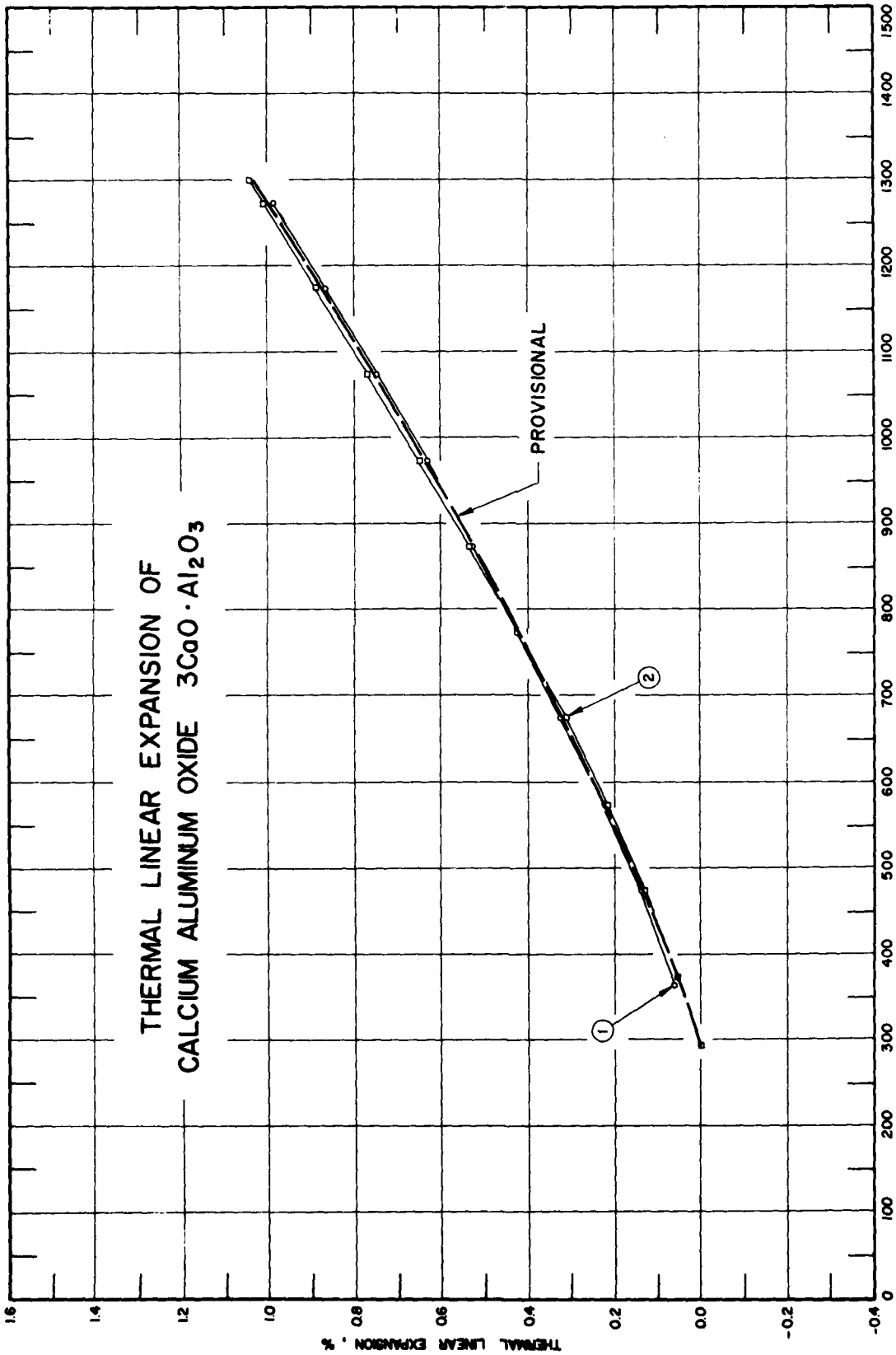

THERMAL LINEAR EXPANSION OF
CALCIUM ALUMINUM OXIDE 3CaO · Al2O3
PROVISIONAL
1
2
THERMAL LINEAR EXPANSION , %
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
TEMPERATURE , K

FIGURE 98

SPECIFICATION TABLE 98. THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $3CaO \cdot Al_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	122	Rigby, G.R. and Green, A.T.	1943	L	373-1473	Artificial mineral	Bar specimen 2 cm diameter; prepared from lime and alumina; heated at 1350-1380 C for 2 hr; second period of 2 hr, repowdered and made into cylinder; refired as before; zero-point correction of 0.062% determined by graphical extrapolation.
2	669	Yanishevskii, V.M., Popova, E.I., and Kuryleva, V.F.	1969	L	373-1273		No details given; data reported by Kantsliz, E. and Ambruz, V. Rzhkhimiya, Summary Vol. No. 9 (1965) cited by authors.

DATA TABLE 98. THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $3CaO \cdot Al_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2	
372	0.062	293	0.000
473	0.140	373	0.055
573	0.224	473	0.132
673	0.326	573	0.218
773	0.422	673	0.314
873	0.527	773	0.420
973	0.637	873	0.533
1073	0.746	973	0.650
1173	0.864	1073	0.770
1273	0.981	1173	0.890
1373	1.096	1273	1.009
1473	1.222	1300	1.042

DATA TABLE 98. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $3CaO \cdot Al_2O_3$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 2*	
293	6.47
373	7.22
473	8.14
573	9.14
673	10.10
773	11.00
873	11.59
973	11.93
1073	12.01
1173	11.98
1273	11.94
1300	11.94

* Not shown in figure.

SPECIFICATION TABLE 99. THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $3CaO \cdot 5Al_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	122	Rigby, G.R. and Green, A.T.	1943	L	373-1473	Artificial mineral	Specimen prepared from lime and alumina; heated at 1803 K; zero-point correction of -0.003% determined by graphical extrapolation.

DATA TABLE 99. THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $3CaO \cdot 5Al_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
*CURVE 1**	
373	-0.003
473	-0.007
573	0.001
673	0.017
773	0.046
873	0.088
973	0.142
1073	0.207
1173	0.278
1273	0.352
1373	0.414
1473	0.497

* No figure given.

SPECIFICATION TABLE 100. THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $5CaO \cdot 3Al_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	122	Rigby, G.R. and Green, A.T.	1943	L	373-1473	Artificial mineral	Appropriate mixture melted in carbon crucible; heated in reducing atmosphere in Hirsch furnace; melted congruently at 1728 K; zero-point correction of 0.042% determined by graphical extrapolation.

DATA TABLE 100. THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM OXIDE $5CaO \cdot 3Al_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
373	0.042
473	0.095
573	0.164
673	0.234
773	0.309
873	0.384
973	0.471
1073	0.557
1173	0.644
1273	0.726
1373	0.821
1473	0.926

* No figure given.

SPECIFICATION TABLE 101. THERMAL LINEAR EXPANSION OF DYSPROSIUM ALUMINUM OXIDE $Dy_2O_3 \cdot 2Al_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	248	Ploetz, G. L., Muccigrosso, A. T., Osika, L. M., and Jacoby, W. R.	1960		303-1273		64.6 Dy_2O_3, 35.4 Al_2O_3; specimen 0.5 in. diameter, 1 in. long; bcc compound; prepared by wet ball milling with flint pebbles for 2 hr, dry pressed at 20 000 psi with 2 wt.% soluble wax emulsion into pellets, and fired in hydrogen atmosphere for 1 hr; m.p. 1820±10 C; density 6.05 g cm^{-3}.

DATA TABLE 101. THERMAL LINEAR EXPANSION OF DYSPROSIUM ALUMINUM OXIDE $Dy_2O_3 \cdot 2Al_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡	
373	0.037	974	0.444
474	0.084	1074	0.525
573	0.145	1173	0.607
674	0.215	1273	0.690
773	0.287		
873	0.364		
923	0.403		

DATA TABLE 101. COEFFICIENT OF THERMAL LINEAR EXPANSION OF DYSPROSIUM ALUMINUM OXIDE $Dy_2O_3 \cdot 2Al_2O_3$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1*,‡	
373	3.66
474	5.62
573	6.71
674	7.11
773	7.56
873	7.77
923	7.77
974	8.16
1074	8.16
1173	8.29
1273	8.38

*No figure given.
‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 102. THERMAL LINEAR EXPANSION OF DYSPROSIUM ALUMINUM OXIDE $3Dy_2O_3 \cdot 5Al_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	86	Philp, J.W., Gonano, R., and Adams, E.D.	1969	E	1.22-4.07	Dysprosium Aluminum Garnet	Specimen 0.65 cm long; cubic structure with complicated unit cell; this curve is here reported using the first given temperature (1.22 K) as reference temperature at which $\Delta L/L_0 = 0$.

*No figure given.

DATA TABLE 102. THERMAL LINEAR EXPANSION OF DYSPROSIUM ALUMINUM OXIDE $3Dy_2O_3 \cdot 5Al_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*, †, ‡		CURVE 1 (cont.)*, †, ‡		CURVE 1 (cont.)*, †, ‡	
1.22	0.000	2.35	0.047	2.82	0.082
1.29	0.001	2.37	0.049	2.88	0.085
1.39	0.004	2.39	0.051	2.93	0.087
1.48	0.006	2.40	0.052	2.98	0.088
1.57	0.008	2.42	0.054	3.02	0.090
1.65	0.010	2.44	0.056	3.08	0.092
1.72	0.013	2.45	0.057	3.14	0.095
1.77	0.014	2.46	0.058	3.17	0.096
1.83	0.016	2.48	0.061	3.31	0.101
2.03	0.025	2.49	0.062	3.37	0.103
2.07	0.027	2.50	0.063	3.43	0.105
2.09	0.029	2.56	0.070	3.50	0.108
2.14	0.032	2.58	0.071	3.80	0.118
2.15	0.032	2.60	0.072	3.90	0.121
2.21	0.036	2.61	0.073	3.98	0.124
2.23	0.038	2.62	0.073	4.07	0.127
2.29	0.042	2.64	0.074		
2.28	0.041	2.65	0.075		
2.27	0.041	2.67	0.076		
2.31	0.044	2.68	0.076		
2.33	0.045	2.71	0.077		
2.34	0.046	2.73	0.078		

DATA TABLE 102. COEFFICIENT OF THERMAL LINEAR EXPANSION OF DYSPROSIUM ALUMINUM OXIDE $3Dy_2O_3 \cdot 5Al_2O_3$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α	T	α
CURVE 1*, ‡		CURVE 1 (cont.)*, ‡		CURVE 1 (cont.)*, ‡		CURVE 1 (cont.)*, ‡		CURVE 1 (cont.)*, ‡	
1.22	0.0185	2.14	0.0647	2.39	0.0953	2.61	0.0539	3.02	0.0385
1.29	0.0212	2.15	0.0668	2.40	0.0985	2.62	0.0528	3.08	0.0388
1.39	0.0229	2.21	0.0659	2.42	0.1038	2.64	0.0515	3.14	0.0378
1.48	0.0254	2.23	0.0731	2.44	0.1058	2.65	0.0508	3.17	0.0362
1.57	0.0277	2.29	0.0761	2.45	0.1109	2.67	0.0478	3.31	0.0361
1.65	0.0303	2.28	0.0788	2.46	0.1148	2.68	0.0460	3.37	0.0366
1.72	0.0326	2.27	0.0810	2.48	0.1229	2.71	0.0452	3.43	0.0351
1.77	0.0343	2.31	0.0808	2.49	0.1281	2.73	0.0430	3.50	0.0344
1.83	0.0370	2.33	0.0841	2.50	0.1360	2.82	0.0411	3.80	0.0335
2.03	0.0515	2.34	0.0873	2.56	0.0750	2.88	0.0403	3.90	0.0339
2.07	0.0539	2.35	0.0881	2.58	0.0576	2.93	0.0392	3.98	0.0329
2.09	0.0583	2.37	0.0929	2.60	0.0566	2.98	0.0390	4.07	0.0324

*No figure given.
†This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 103. THERMAL LINEAR EXPANSION OF LEAD ALUMINUM OXIDE $PbO \cdot Al_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	286	Argyle, J. F. and Hummel, F. A.	1963		303-1027		Specimen prepared from Cp chemicals hand mixed with acetone for 15 to 20 min, air dried, heated slowly to 573 K for 4 hr, remixed, recalcined at 1023 K for 24 hr, cooled, remixed, recalcined at 1173 K for 12 hr, ground mixed with carbowax solution, nodulized through 20-mesh seive, pressed into 10 x 1 x 1 cm bars at 1000 psi, and fired slowly to 1173 K for 6 hr; original length 92.5 mm; measured with heating rate of 393 K per hr.

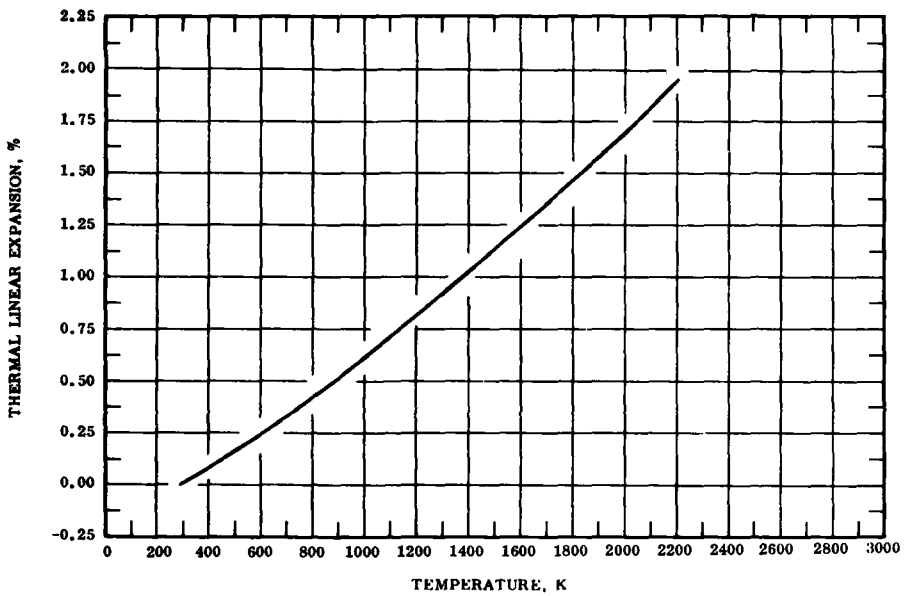
DATA TABLE 103. THERMAL LINEAR EXPANSION OF LEAD ALUMINUM OXIDE $PbO \cdot Al_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 1 (cont.)*	
303	0.005	790	0.310
344	0.025	808	0.323
365	0.038	835	0.336
375	0.043	847	0.347
399	0.057	875	0.367
421	0.068	885	0.374
464	0.098	915	0.395
478	0.106	926	0.402
519	0.134	948	0.420
566	0.167	974	0.434
605	0.188	990	0.438
625	0.203	1015	0.456
655	0.230	1027	0.453
701	0.255		
716	0.261		
752	0.285		
764	0.296		

* No figure given.

FIGURE AND TABLE NO. 104R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF MAGNESIUM ALUMINUM OXIDE $MgO \cdot Al_2O_3$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	7.0
400	0.078	7.5
600	0.240	8.4
800	0.412	9.1
1000	0.602	9.8
1200	0.804	10.4
1400	1.020	10.9
1600	1.237	11.2
1800	1.465	11.5
2000	1.696	11.7
2200	1.930	11.8

REMARKS

The recommended values are based on the data for the pure spinel sample measured by the x-ray method (Curves 4, 5 and 12). These values are considered accurate to within ±3% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.183 + 5.456 \times 10^{-4}\, T + 2.808 \times 10^{-7}\, T^2 - 4.181 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are primarily derived by differentiating the above equation and are considered accurate to about ±5%.

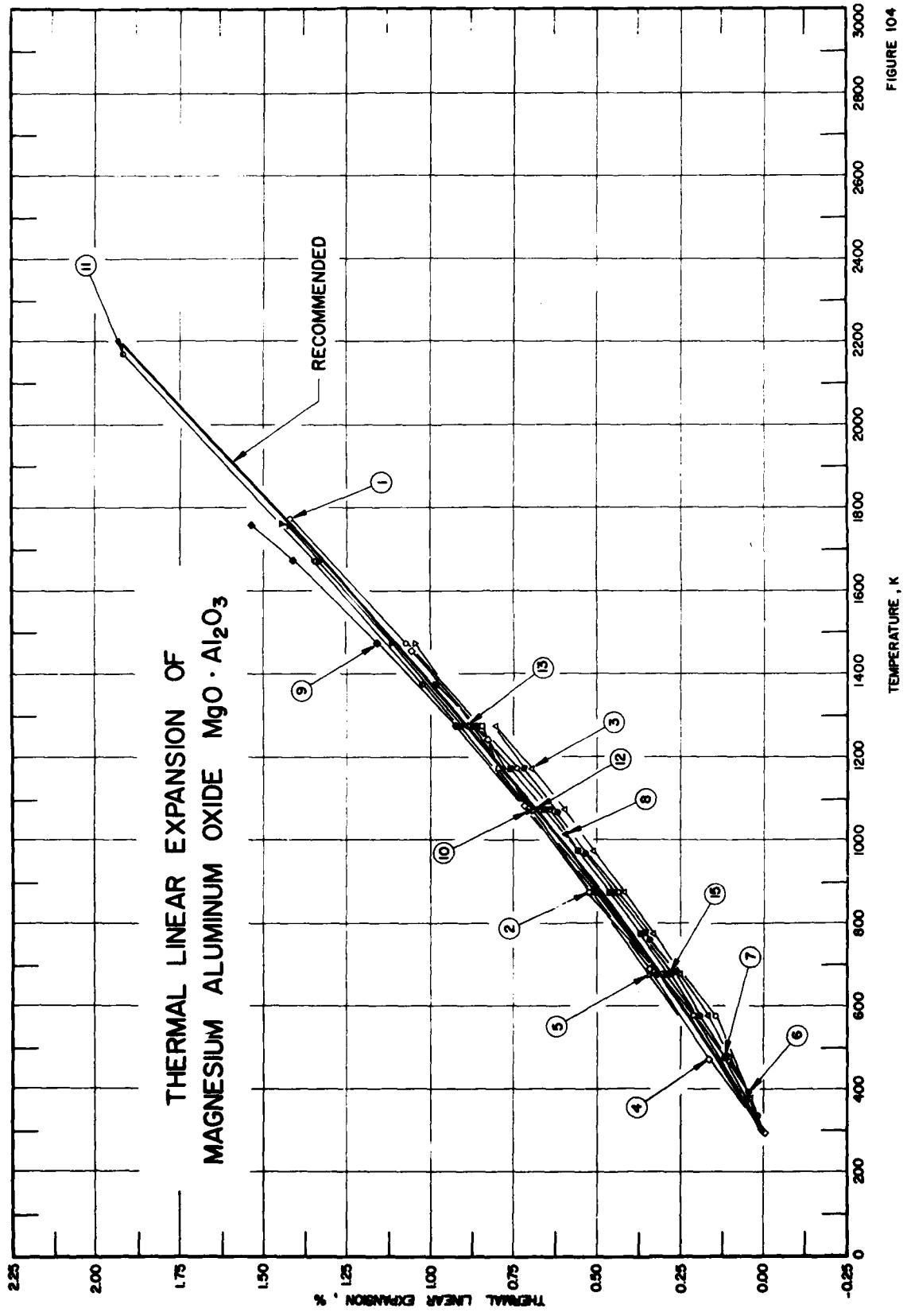

THERMAL LINEAR EXPANSION OF
MAGNESIUM ALUMINUM OXIDE MgO · Al2O3
RECOMMENDED
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000

FIGURE 104

SPECIFICATION TABLE 104. THERMAL LINEAR EXPANSION OF MAGNESIUM ALUMINUM OXIDE $MgO \cdot Al_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	298-1773		Specimen with cross section 0.5 x 0.5 in. and 7 in. long; coarse fused grain; the ends sawed at a rake and to a point.
2	146	Scheetz, H.	1961		298-1273		Polycrystalline bar specimen; density 3.28 g cm^{-3}; porosity 8.4%.
3	18	Floyd, J.R.*	1964		298-1273	Spinel	Specimen 0.25 in. diameter, 4 in. long; prepared from calcined alumina and $MgCO_3$ wet mixed in 3000 g batches for 24 hrs with 4500 g of 1 in. diameter alumina balls in 5.5 qt. alumina mills, dried to 473 K, formed into pressing granules using organic binder, dry pressed, fired to 1923 K at average heating rate of 373 K per hr, soaked for 3 hr, and cooled at average rate of 373 K per hr.
4	155	Zimmerman, W.F. and Allen, A.W.	1956	X	291-1455	Spinel	Expansion measured using CoKα x-radiation in back-reflection high temperature camera.
5	74	Beals, R.J. and Cook, R.L.	1957	X	293-1473	Spinel	Specimen prepared from reagent grade materials; cubic structured powder specimen; data from smoothed curve.
6	162	Paladino, A.E. and Snider, C.R.	1970	L	337-1271		Grade A powder hot pressed 30 min at 6000 psi and 1873 K under 10^{-4} torr atmosphere; annealed 20 hrs at 1723 K.
7	97	Rigby, G.R., Lovell, G.H.B., and Green, A.T.	1946		373-1473	Spinel	Cylindrical specimen 2 cm diameter; prepared by mixing MgO, Al_2O_3 in proportions; 5% boric acid added, molded to bar with gum arabic, fired to 1530 C for 2 hrs, reheated to 1530 C.
8	242	Bailey, J.T. and Russell, R.	1968	L	288-1013	Spinel	Data from smoothed curve; zero-point correction of ±0.000% determined by graphical interpolation.
9	23	Nielson, T.H. and Leipold, M.H.	1962	L	298-1760	HP144 Magnesium Aluminate Spinel	Specimen 3 in. long; grain size 36 ±4 μ; 99.5 pure raw material obtained from Fisher Scientific Co.; electronic grade M-300 magnesium oxide, Linde A-5175 alpha aluminum oxide; milled 4 hr; hot-pressed at 3250 psi, 1723 K for 30 min; 97.0% theoretical density; expansion measured in air atmosphere.
10	23	Nielsen, T.H. and Leipold, M.H.	1962	L	1763-298	HP144 Magnesium Aluminate Spinel	The above specimen; expansion measured with decreasing temperature.
11	23	Nielsen, T.H. and Leipold, M.H.	1962	L	298-2173	HP144 Magnesium Aluminate Spinel	The above specimen; grain size 53 ±4 μ; 91.0% theoretical density; expansion measured on second test.
12	33	Kirchner, H.P. and Gruver, R.M.	1965	X	298-1273	Spinel	65.3 Al_2O_3, 34.7 MgO; raw materials ground and mixed, forced through 200 mesh screen; binder added, then pressed and fired, ground in mortar and pestle; incomplete spinel formation obeerved.
13	33	Kirchner, H.P. and Gruver, R.M.	1965	X	298-1273	Spinel	65.9 Al_2O_3, 34.1 MgO; similar to the above specimen.
14*	33	Kirchner, H.P. and Gruver, R.M.	1965	X	298-1273	Spinel	67.4 Al_2O_3, 32.6 MgO; similar to the above specimen.
15	33	Kirchner, H.P. and Gruver, R.M.	1965	X	298-1273	Spinel	76.8 Al_2O_3, 23.2 MgO; similar to the above specimen.
16*	33	Kirchner, H.P. and Gruver, R.M.	1965	X	298-1273	Spinel	76.8 Al_2O_3, 23.2 MgO; similar to the above specimen.
17*	33	Kirchner, H.P. and Gruver, R.M.	1965	X	298-1273	Spinel	82.4 Al_2O_3, 17.6 MgO; similar to the above specimen.

*Not shown in figure.

DATA TABLE 104. THERMAL LINEAR EXPANSION OF MAGNESIUM ALUMINUM OXIDE $MgO \cdot Al_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.003
573	0.146
873	0.434
1173	0.738
1473	1.072
1773	1.419
CURVE 2	
298	0.004*
573	0.213
673	0.308
873	0.522
1173	0.792
1273	0.843
CURVE 3	
298	0.001*
373	0.035
473	0.101
573	0.171
673	0.253
773	0.333
873	0.419
973	0.511
1073	0.597
1173	0.695
1273	0.805
CURVE 4	
291	-0.002
469	0.170
685	0.342
873	0.525*
1083	0.718
1242	0.826
1455	1.052
CURVE 5	
304	0.010
473	0.169*
673	0.344
873	0.520*
CURVE 5 (cont.)*	
1073	0.692
1273	0.869
1473	1.042
CURVE 6	
337	0.022
390	0.049
474	0.103*
579	0.188
680	0.267
760	0.342
774	0.359
874	0.449
968	0.532
1069	0.622
1178	0.719
1271	0.811*
CURVE 7	
373	0.05
473	0.12
573	0.20*
673	0.29
773	0.37
873	0.46
973	0.56
1073	0.66
1173	0.76
1273	0.86
1373	0.98
1473	1.07*
CURVE 8	
288	0.000*
373	0.057*
472	0.125*
573	0.205*
673	0.288*
773	0.376*
873	0.466*
973	0.560*
1013	0.598
CURVE 9	
298	0.004*
673	0.319
873	0.509
1273	0.924
1473	1.160
1673	1.410
1760	1.530
CURVE 10	
1763	1.442
1760	1.423
1673	1.326
1473	1.119
1273	0.904
1073	0.704
873	0.504*
673	0.319*
298	0.004*
CURVE 11	
298	0.004*
673	0.315*
873	0.494
1073	0.690*
1273	0.904*
1374	1.020
1473	1.120*
1674	1.340
2173	1.920
CURVE 12	
298	0.003*
473	0.126*
673	0.294*
873	0.473*
1073	0.673
1273	0.901*
CURVE 13	
298	0.004*
473	0.127*
673	0.296*
CURVE 13 (cont.)	
873	0.483*
1073	0.687*
1273	0.891
CURVE 14*	
298	0.003
473	0.122
673	0.287
873	0.471
1073	0.664
1273	0.858
CURVE 15	
298	0.003*
473	0.118*
673	0.278
873	0.458*
1073	0.645
1273	0.839*
CURVE 16*	
298	0.003
473	0.118
673	0.281
1073	0.649
1273	0.850
CURVE 17*	
298	0.003
473	0.118
673	0.271
873	0.443
1073	0.626
1273	0.833

*Not shown in figure.

SPECIFICATION TABLE 105. THERMAL LINEAR EXPANSION OF MANGANESE ALUMINUM OXIDE $MnO \cdot Al_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	94	Brooksbank, D. and Andrews, K.W.	1968	X	296-974		Specimen prepared from 59 Al_2O_3, 41 MnO; heated in vacuo to 1693 K; expansion measured using $CrK\alpha$ radiation; lattice parameter reported at 296 K is 8.2100 Å; 8.2098 Å at 293 K determined by graphical extrapolation.
2*	671	Avetikov, V.G., Fadeeva, V.I., and Frenkel, E.B.	1969	X	1473-1723	$MnAl_2O_4$	Samples prepared in the form of tablets by cold pressing and subsequent sintering at various temperatures in the range 800-1500 K; 2 hr soak at 1200 K; lattice parameter reported at 1473 K is 8.291 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 105. THERMAL LINEAR EXPANSION OF MANGANESE ALUMINUM OXIDE $MnO \cdot Al_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
296	0.002
376	0.075
472	0.143
572	0.224
673	0.303
775	0.395
874	0.459
974	0.536
CURVE 2*,†	
1473	0.000
1534	-0.145
1625	-0.253
1675	-0.386
1723	-0.398

* No figure given.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

SPECIFICATION TABLE 106. THERMAL LINEAR EXPANSION OF NICKEL ALUMINUM OXIDE $NiO \cdot Al_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	134	Gilliam, E. and Holden, J. P.	1963	X	293-1493	Nickel Aluminate	Nickel particles about 1 μ in size oxidized in air atmosphere at 973 K, wetted with aluminum nitrate solution, dired at 373 K; mixture decomposed to mixed oxides, ignited at 1573 K 1 hr in air atmosphere, then cooled; unit cell reported at 293 K is 8.0481 Å.

DATA TABLE 106. THERMAL LINEAR EXPANSION OF NICKEL ALUMINUM OXIDE $NiO \cdot Al_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.0000
443	0.0869
565	0.1714
599	0.2000
642	0.2373
932	0.4845
1285	0.8064
1493	1.0275

* No figure given.

SPECIFICATION TABLE 107. THERMAL LINEAR EXPANSION OF ZINC ALUMINUM OXIDE $ZnO \cdot Al_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	74	Beals, R.J. and Cook, R.L.	1957	X	299-1473		Specimen prepared from reagent grade materials; powder specimen showing cubic structure; data from smoothed curve; zero-point correction of 0.006% determined by graphical extrapolation.

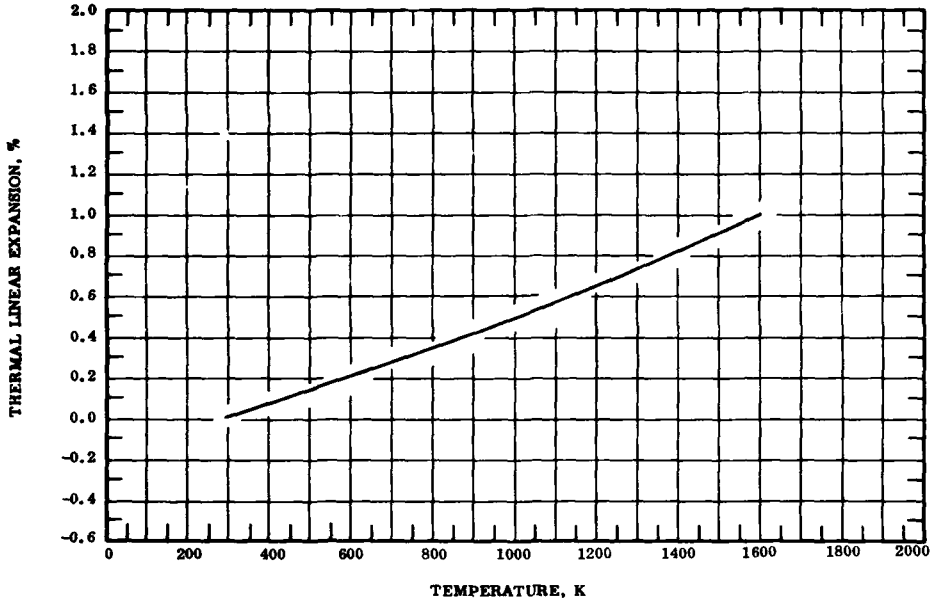
DATA TABLE 107. THERMAL LINEAR EXPANSION OF ZINC ALUMINUM OXIDE $ZnO \cdot Al_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
299	0.006
473	0.166
673	0.335
873	0.505
1073	0.666
1273	0.855
1473	1.068

* No figure given.

FIGURE AND TABLE NO. 108R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF MAGNESIUM CHROMIUM OXIDE $MgO \cdot Cr_2O_3$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	6.2
400	0.067	6.4
500	0.132	6.6
600	0.200	6.7
700	0.267	6.9
800	0.337	7.2
900	0.410	7.4
1000	0.485	7.6
1100	0.563	7.9
1200	0.643	8.2
1300	0.727	8.5
1400	0.815	8.8
1500	0.902	9.1
1600	0.994	9.4

REMARKS

The recommended values are based on the data for the pure samples and are considered accurate to within ±3% at temperatures below 1100 K and ±5% above 1100 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.176 + 5.822 \times 10^{-4}\, T + 5.580 \times 10^{-8}\, T^2 + 2.336 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ±5%.

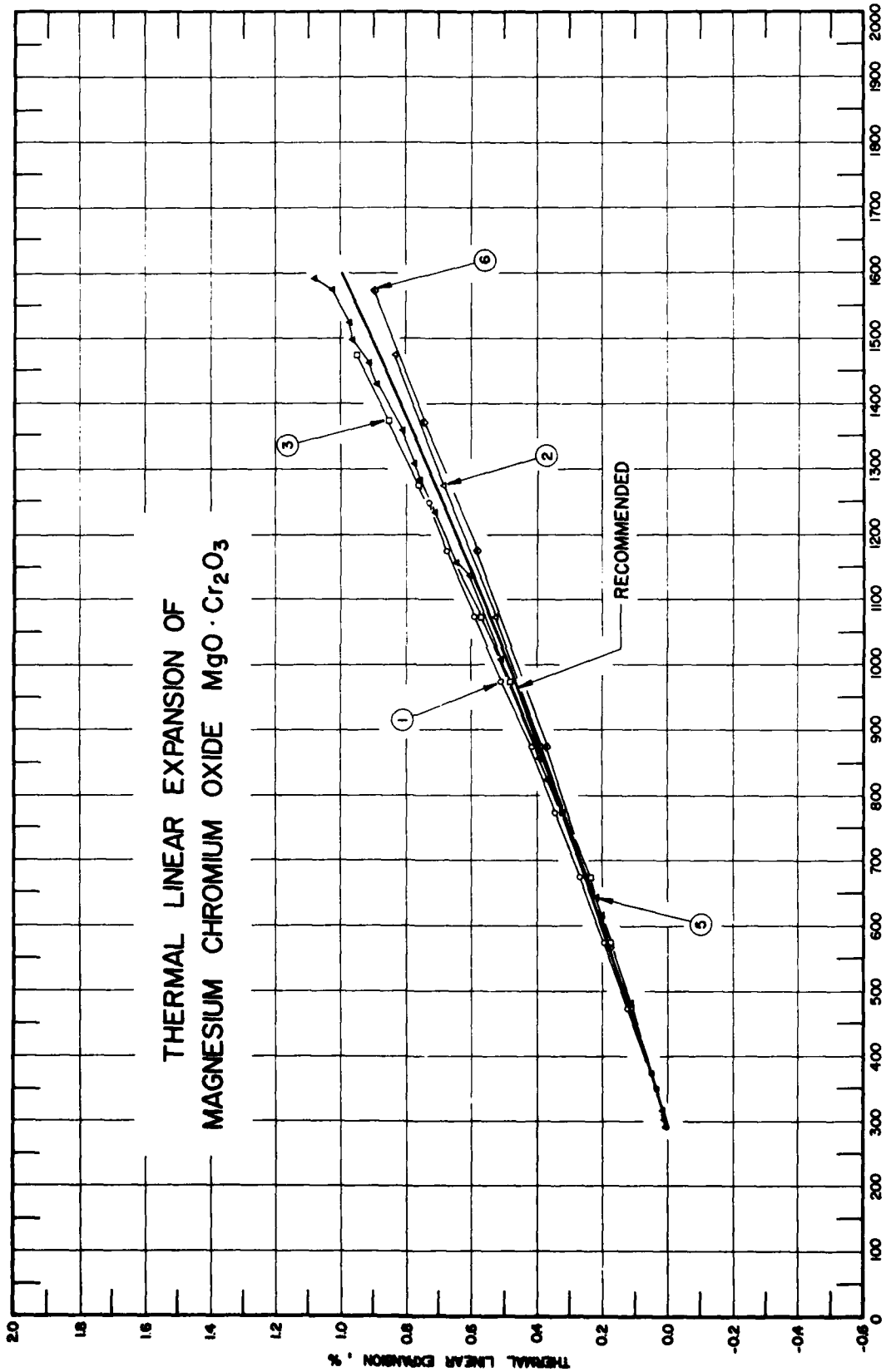

THERMAL LINEAR EXPANSION OF
MAGNESIUM CHROMIUM OXIDE $MgO \cdot Cr_2O_3$
RECOMMENDED
1
2
3
5
6
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 108

SPECIFICATION TABLE 108. THERMAL LINEAR EXPANSION OF MAGNESIUM CHROMIUM OXIDE $MgO \cdot Cr_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	95	Williams, R.M.	1967	L	350-1247		Specimen prepared by mixing chemically pure $Cr(NO_3) \cdot 9H_2O$ and $Mg(NO_3)_2 \cdot 6H_2O$, heated and melted in water of crystallization; water evaporated off, further heating and various oxides of nitrogen given off; calcined 1 hr at 1623 K after 6 hr of slow heating; mixed thoroughly and fired 1 hr at 1673 K; specimen prepared in bar form 5.93 x 1.27 x 0.95 cm by hydraulic pressing at 5000, 10000 and 15,000 psi; fired after slow heating 2 hr at 1873 K.
2	74	Beals, R.J. and Cook, R.L.	1957	X	304-1473		Spinel specimen; prepared from reagent grade materials; cubic structured powder specimen.
3	97	Rigby, G.R., Lovell, G.H.B., and Green, A.T.	1946		373-1473	picrochromite	Specimen prepared by mixing MgO, Cr_2O_3 in proportion and 5% boric acid, molded into bar with gum arabic, fired to 1530 C twice, cylinder form of 2 cm diameter reheated to 1530 C.
4*	128	Wisely, H.K.	1962	L	373-973		Bar specimen 0.25 x 0.375 x 2 in.; prepared from 79.04 Cr_2O_3, 20.96 MgO under pressure 26,000 psi; sintered at 1400 C for 16 hr in air atmosphere; reported error ±1%.
5	974	Vishnevskii, I.I. and Alapin, B.G.	1970	X	293-1591	$MgCr_2O_4$	Refractory crystalline substances; lattice parameter measured; 8.3194 Å reported at room temperature; data from heating and cooling measurement; lattice parameter reported at 293 K is 8.333 Å.
6	673	Kapralik, I.	1969	X	293-1573	$MgCr_2O_4$	Cubic spinels $MgCr_2O_4$; synthesized from Cr_2O_3 and $MgCO_3$; Cr_2O_3; heated 12 hr at 1473 K; $MgCO_3$ heated 12 hr at 1623 K; lattice parameter measured; 8.2375 Å reported at 293 K.

* Not shown in figure.

DATA TABLE 108. THERMAL LINEAR EXPANSION OF MAGNESIUM CHROMIUM OXIDE $MgO \cdot Cr_2O_3$

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %)

T	$\Delta L/L_0$
CURVE 1	
350	0.032
373	0.045
473	0.120
573	0.189
673	0.262
773	0.341
873	0.419
973	0.504
1073	0.588
1173	0.673
1247	0.729
CURVE 2	
304	0.007
473	0.114
673	0.244
873	0.386
1073	0.528
1273	0.681
1473	0.836
CURVE 3	
373	0.05*
473	0.11*
573	0.17
673	0.24
773	0.32
873	0.39*
973	0.48
1073	0.57
1173	0.67*
1273	0.76
1373	0.85
1473	0.95
CURVE 4*	
373	0.05
673	0.25
973	0.48

T	$\Delta L/L_0$
CURVE 5	
293	0.000
319	0.010
481	0.107
618	0.199
643	0.214
824	0.367
858	0.389
975	0.486
1009	0.506
1072	0.571*
1138	0.602
1158	0.643
1233	0.707
1282	0.756
1307	0.772
1358	0.814
1428	0.889
1462	0.913
1496	0.960
1524	0.974
1575	1.028
1591	1.080
CURVE 6	
293	0.000*
568	0.172
874	0.363
1175	0.581
1371	0.742
1573	0.896

* Not shown in figure.

SPECIFICATION TABLE 109. THERMAL LINEAR EXPANSION OF ZIRCONIUM CHROMIUM OXIDE $ZrO_2 \cdot Cr_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	91	Hummel, F.A.	1946		296-1073		Specimen prepared by adding ammonium dichromate to solution of zirconium acetate; thoroughly washed and heated to give chromite; calcined at 1873 K.

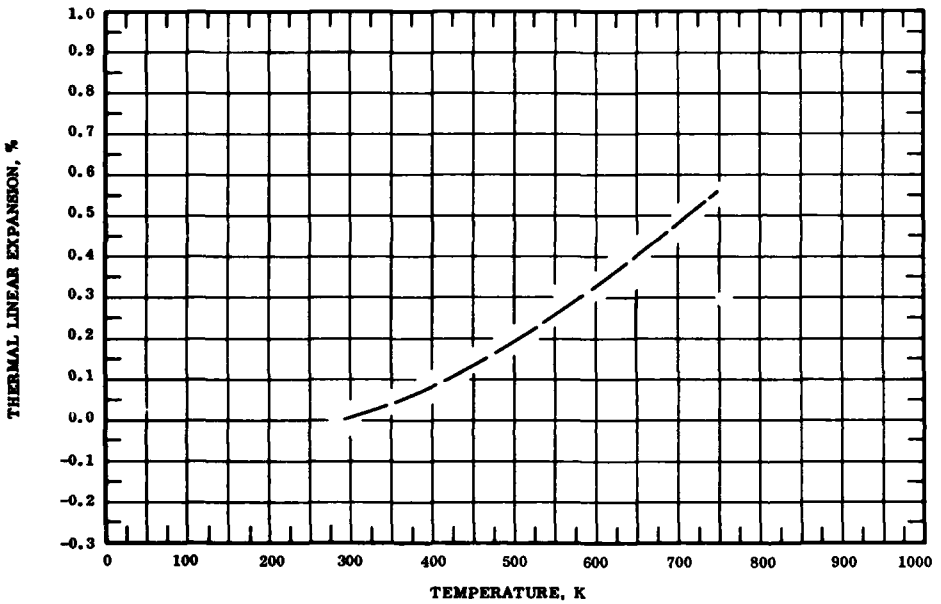
DATA TABLE 109. THERMAL LINEAR EXPANSION OF ZIRCONIUM CHROMIUM OXIDE $ZrO_2 \cdot Cr_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
296	0.001
322	0.013
371	0.036
420	0.064
471	0.098
521	0.128
571	0.156
621	0.181
671	0.209
720	0.239
770	0.271
821	0.310
871	0.350
924	0.390
974	0.424
1024	0.457
1073	0.487

* No figure given.

FIGURE AND TABLE NO. 110R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF LEAD GERMANIUM OXIDE $2PbO \cdot GeO_2$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, $10^{-6}\ K^{-1}$]

T	$\Delta L/L_0$	α
293	0.000	5.0
350	0.038	7.6
400	0.079	9.6
450	0.131	11.3
500	0.191	12.6
550	0.257	13.7
600	0.328	14.4
650	0.401	14.9
700	0.476	15.0
750	0.551	15.0

REMARKS

The provisional values are considered accurate to within ±7% and are represented approximately by the following equation:

$$\Delta L/L_0 = 0.117 - 1.471 \times 10^{-3}\ T + 4.252 \times 10^{-6}\ T^2 - 2.026 \times 10^{-9}\ T^3$$

The tabulated values for the coefficient of thermal expansion are primarily derived by differentiating the above equation and are considered accurate to about ±7%.

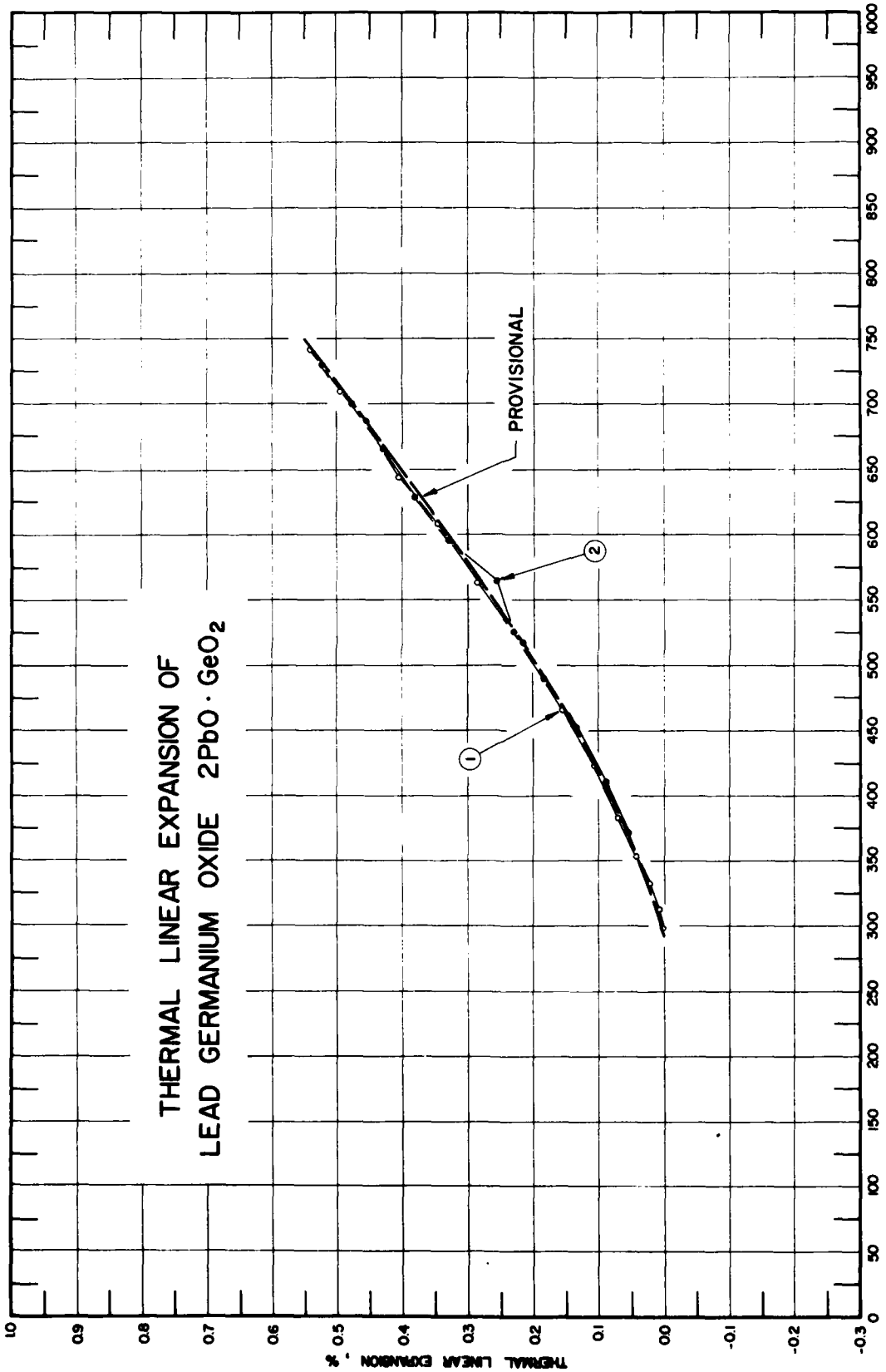

THERMAL LINEAR EXPANSION OF
LEAD GERMANIUM OXIDE 2PbO · GeO2
PROVISIONAL
1
2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 110

SPECIFICATION TABLE 110. THERMAL LINEAR EXPANSION OF LEAD GERMANIUM OXIDE $2PbO \cdot GeO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	286	Arggle, J.F. and Hummel, F.A.	1963	X	293-783	Pb_2GeO_4	81.02 PbO and 18.98 GeO_2 (calculated composition); specimen prepared from Cp chemicals hand mixed with acetone for 15 to 20 min., air dried, heated slowly to 573 K for 4 hr, remixed, calcined at 673 K for 24 hr, cooled, remixed recalcined at 753 K for 12 hr, ground, mixed with Carbowax solution, modulized through a 20-mesh sieve, pressed into 10 by 1 by 1 cm bars at 1000 psi, and fired slowly to 753 K for 6 hr; original length 102.8 mm; measured with heating rate of 120 C per hr.
2	286	Arggle, J.F. and Hummel, F.A.	1963	X	293-751	Pb_2GeO_4	Second run of above specimen.

DATA TABLE 110. THERMAL LINEAR EXPANSION OF LEAD GERMANIUM OXIDE $2PbO \cdot GeO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2	
298	0.003	298	0.001*
313	0.010	313	0.008*
333	0.025	333	0.026*
354	0.042	372	0.055
383	0.067	411	0.090
424	0.102	453	0.134
467	0.153	490	0.184
519	0.218	527	0.231
564	0.285	564	0.258
609	0.349	597	0.332
645	0.406	629	0.382
687	0.457	666	0.431
710	0.495	701	0.478
743	0.541	730	0.525
		743	0.542*

* Not shown in figure.

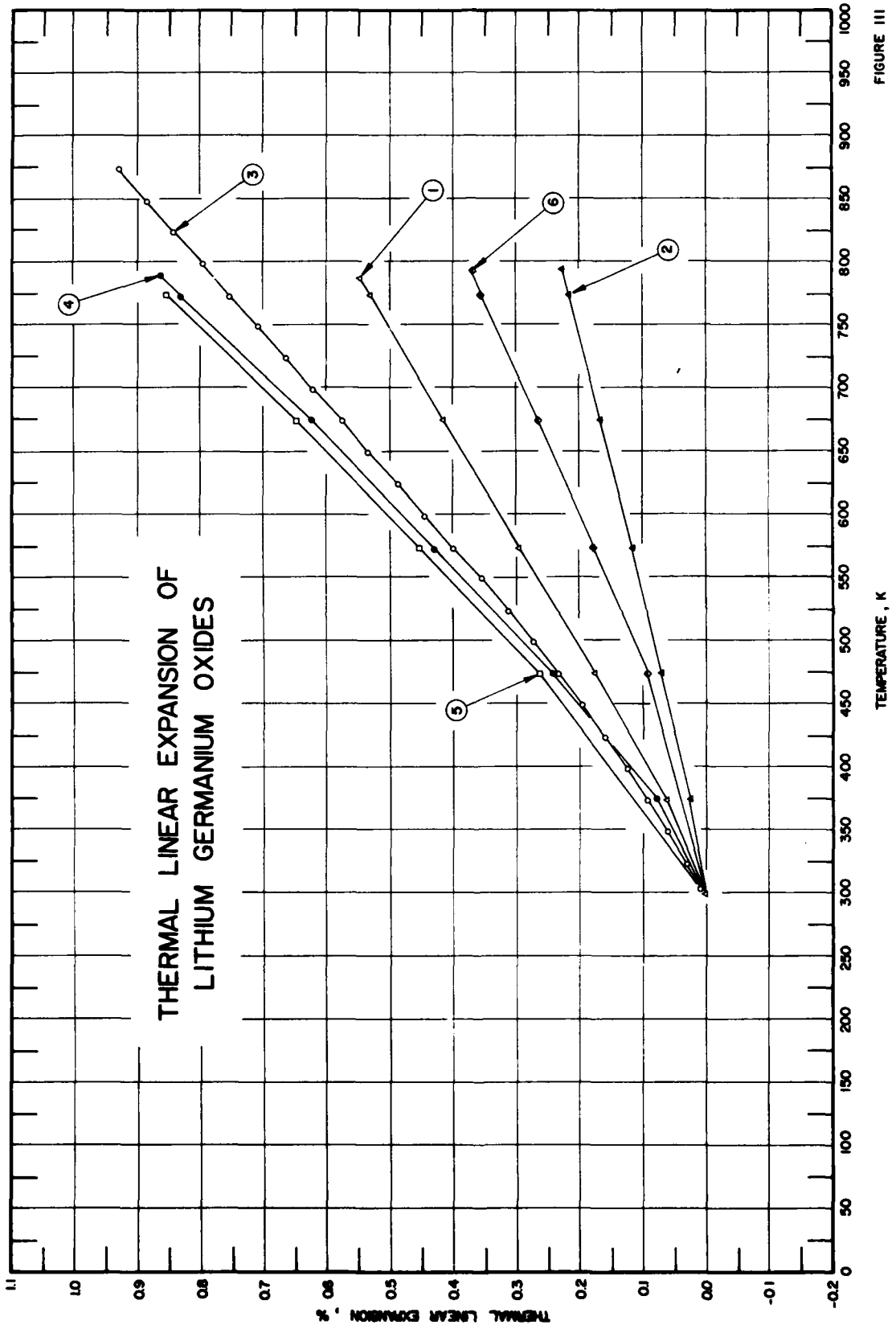

THERMAL LINEAR EXPANSION OF
LITHIUM GERMANIUM OXIDES
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1
2
3
4
5
6

FIGURE III

SPECIFICATION TABLE 111. THERMAL LINEAR EXPANSION OF LITHIUM GERMANIUM OXIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	975	Murthy, M.K. and Ip, J.	1964	L	298-787	$Li_2O \cdot GeO_2$	Lithium germanium oxide; 25.0 Li_2O and 75.0 GeO_2; crystalline phase; specimen prepared from Fisher-Certified reagent grade Li_2CO_3 and electronic-grade GeO_2 (from Eagle Picker Co.), wet-mixed in alcohol, dried at 383 K solid-state reacted at about 1273 K to 1323 K cooled in air, reheated for about 10 min., and quenching by dipping in water, density at 30 C, 3.51 g cm^{-3}; melting point 1518 K.
2	975	Murthy, M.K. and Ip, J.	1964	L	298-793	$Li_2O \cdot 7GeO_2$	Lithium germanium oxide; 3.9 Li_2O and 96.1 GeO_2; crystalline phase; specimen prepared from Fisher-Certified reagent grade Li_2CO_3 and electronic grade GeO_2 (from Eagle Picker Co.) wet-mixed in alcohol, dried at 383 K, melted at about 1373 K to 1523 K, cooled in air, reheated for about 10 min., and quenched by dipping in water; density at 303 K, 3.96 g cm^{-3}; melting point 1306 K.
3	311	Soga, N.	1964		303-873	$2Li_2O \cdot GeO_2$	Lithium germanium oxide; specimen prepared from Fisher-Certified reagent grade Li_2CO_3 and electronic grade GeO_2 (from Allied Chemical Corp.), wet mixed under alcohol, heated at 393 K per hr to 1473 K, held at 1473 K for 20 hr, pressed at 5000 psi, and retired at 1473 K for 3 hr; measured with heating rate of 2.5 C per min.
4	975	Murthy, M.K. and Ip, J.	1964	L	298-789	$2Li_2O \cdot GeO_2$	Lithium germanium oxide; 36.4 Li_2O and 63.6 GeO_2; crystalline phase; specimen prepared from Fisher-Certified reagent grade Li_2CO_3 and electronic grade GeO_2 (from Eagle Picker Co.), wet-mixed in alcohol, dried at 383 K, solid-state reacted at about 1273 K to 1323 K, cooled in air, reheated for about 10 min., and quenched by dipping in water; density at 303 K, 2.57 g cm^{-3}; melting point 1553 K.
5	975	Murthy, M.K. and Ip, J.	1964		298-773	$3Li_2O \cdot 2GeO_2$	Lithium germanium oxide; 30.0 Li_2O and 70.0 GeO_2; crystalline phase; specimen prepared from Fisher-Certified reagent grade Li_2CO_3 and electronic grade GeO_2 (from Eagle Picker Co.) wet-mixed in alcohol, dried at 383 K, solid-state reacted at about 1273 K to 1323 K, cooled in air, reheated for about 10 min., and quenched by dipping in water; density at 303 K, 2.88 g cm^{-3}; melting point 1398 K.
6	975	Murthy, M.K. and Ip, J.	1964	L	298-793	$3Li_2O \cdot 8GeO_2$	Lithium germanium oxide; 9.8 Li_2O and 90.2 GeO_2; crystalline phase; specimen prepared from Fisher-Certified reagent grade Li_2CO_3 and electronic grade GeO_2 (from Eagle Picker Co.) wet-mixed in alcohol, dried at 383 K, melted at about 1373 K to 1523 K, cooled in air, reheated for about 10 min., and quenched by dipping in water; density at 303 K, 4.20 g cm^{-3}; melting point 1226 K.

DATA TABLE 111. THERMAL LINEAR EXPANSION OF LITHIUM GERMANIUM OXIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.002
373	0.062
473	0.178
573	0.298
673	0.416
773	0.530
787	0.548
CURVE 2	
298	0.0006*
373	0.0266
473	0.0726
573	0.1186
673	0.1686
773	0.2166
793	0.2266
CURVE 3	
303	0.010
323	0.031
348	0.061
373	0.093
398	0.126
423	0.160
448	0.196
473	0.234
498	0.273
523	0.313
548	0.356
573	0.400
598	0.444
623	0.488
648	0.533
673	0.576
698	0.621
723	0.665
748	0.710
773	0.753
798	0.797
823	0.842
848	0.886
873	0.930
CURVE 4	
298	0.003*
373	0.081
473	0.244
573	0.431
673	0.627
773	0.831
789	0.863
CURVE 5	
298	0.004*
373	0.096*
473	0.264
573	0.452
673	0.648
773	0.852
CURVE 6	
298	0.000*
373	0.024*
473	0.094
573	0.178
673	0.266
773	0.354
793	0.370

* Not shown in figure.

SPECIFICATION TABLE 112. THERMAL LINEAR EXPANSION OF MAGNESIUM GERMANIUM OXIDE $2MgO \cdot GeO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	128	Wisely, H.R.	1962	L	373-973		Bar specimen, 1 in. by 3/4 in. by 1/4 in. pressed under pressure 26,000 psi; sintered 2 hr at 1300 C; no MgO or GeO_2 by x-ray identification; reported error ±3%.

DATA TABLE 112. THERMAL LINEAR EXPANSION OF MAGNESIUM GERMANIUM OXIDE $2MgO \cdot GeO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
373	0.083
673	0.395
973	0.737

* No figure given.

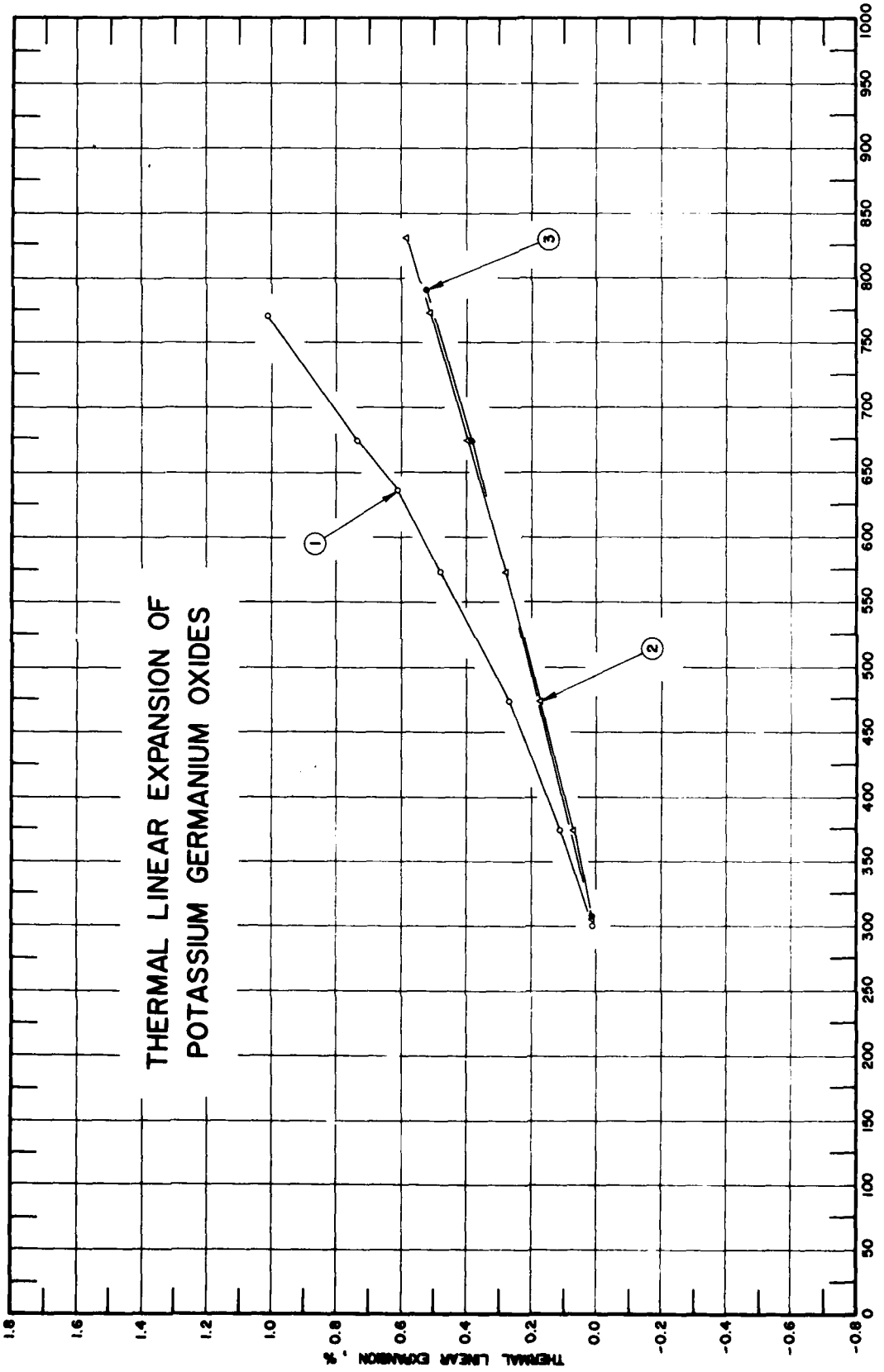

THERMAL LINEAR EXPANSION OF
POTASSIUM GERMANIUM OXIDES
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1
2
3
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 113

SPECIFICATION TABLE 113. THERMAL LINEAR EXPANSION OF POTASSIUM GERMANIUM OXIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	249	Murthy, M.K., Long, L., and Ip, J.	1968	L	300-771	$K_2O \cdot 2GeO_2$	Potassium germanium oxide; electronic grade GeO_2 from Eagle Picher Industries Inc.; and reagent grade K_2CO_3 from Fisher Scientific Co.; wet-mixed in alcohol in mortar, melted, cooled, crushed and stored in dessicator.
2	249	Murthy, M.K., Long, L., and Ip, J.	1968	L	305-830	$K_2O \cdot 7GeO_2$	Potassium germanium oxide; electronic grade GeO_2 from Eagle Picher Industries, Inc., and reagent grade K_2CO_3 from Fisher Scientific Co.; wet-mixed in alcohol in mortar, melted, cooled, crushed and stored in dessicator.
3	249	Murthy, M.K., Long, L., and Ip, J.	1968	L	307-791	$3K_2O \cdot 11GeO_2$	Potassium germanium oxide; electronic grade GeO_2 from Eagle Picher Industries, Inc., and reagent grade K_2CO_3 from Fisher Scientific Co., wet-mixed in alcohol in mortar, melted, cooled, crushed and stored in dessicator.

DATA TABLE 113. THERMAL LINEAR EXPANSION OF POTASSIUM GERMANIUM OXIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
300.0	0.010
374	0.111
473	0.268
573	0.480
636	0.611
673	0.737
771	1.010
CURVE 2	
305	0.010
373	0.066
473	0.172
573	0.279
673	0.395
773	0.513
830	0.582
CURVE 3	
307	0.011
373	0.060*
473	0.168*
573	0.277*
673	0.389
773	0.507
791	0.528

* Not shown in figure.

SPECIFICATION TABLE 114. THERMAL LINEAR EXPANSION OF ZINC GERMANIUM OXIDE $2ZnO \cdot GeO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	314	Wen, Pu-Yi, Brown, J.J., and Hummel, F.A.	1964	X	293-1303	Sample B1	60.88 ZnO and 39.12 GeO_2; specimen prepared from C.P. grade ZnO and GeO_2 mixed together, dried, and heat treated; expansion measured along a-axis by x-ray diffraction.
2*	314	Wen, Pu-Yi, et al.	1964	X	293-1303	Sample B1	The above specimen except expansion measured along c-axis.
3*	314	Wen, Pu-Yi, et al.	1964	L	293-1257	Sample B1	60.88 ZnO and 39.12 GeO_2; specimen prepared from C.P. grade, ZnO and GeO_2 mixed together, dried, pressed into 1 cm by 1 cm by 10 cm bars at 500 psi, and heat treated; aggregate expansion measured with heating rate of 125 C per hr.

DATA TABLE 114. THERMAL LINEAR EXPANSION OF ZINC GERMANIUM OXIDE $2ZnO \cdot GeO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 3*	
293	0.000	293	0.000
583	0.007	473	0.012
856	0.098	757	0.068
961	0.091	973	0.124
1303	0.211	1257	0.216
CURVE 2*			
293	0.000		
583	0.105		
856	0.168		
961	0.220		
1303	0.346		

* No figure given.

SPECIFICATION TABLE 115. THERMAL LINEAR EXPANSION OF CALCIUM HAFNIUM OXIDE $CaO \cdot HfO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	113	Curtis, C.E., Doney, L.M., and Johnson, J.R.	1954	L	373-1573		Orthorhombic structure specimen of 3 x 0.5 x 0.125 in.; small dry-pressed bar under 20,000 psi; prepared from an equimolecular composition of CaO and hafnia (<0.2 reported impurities); fired at 1550 C for 2 hr and allowed to cool slowly; heating rate 3 C/min.

DATA TABLE 115. THERMAL LINEAR EXPANSION OF CALCIUM HAFNIUM OXIDE $CaO \cdot HfO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
373	0.028
873	0.208
1573	1.056

* No figure given.

SPECIFICATION TABLE 116. THERMAL LINEAR EXPANSION OF STRONTIUM HAFNIUM OXIDE $SrO \cdot HfO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	935	Berizhnoi, A.S. and Bilik, V.Ya.	1967		273-1473		Method of preparation of the specimen and the experimental method are not given.

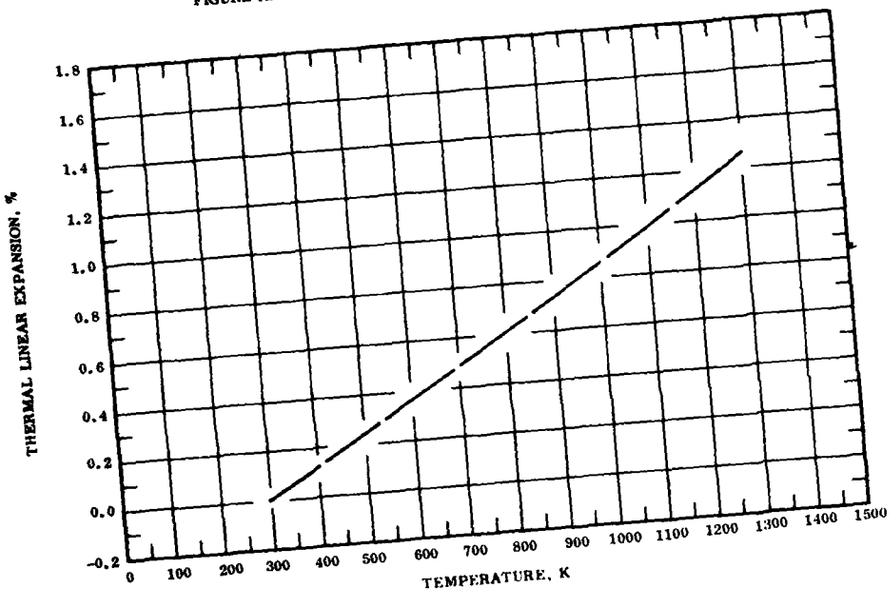
DATA TABLE 116. THERMAL LINEAR EXPANSION OF STRONTIUM HAFNIUM OXIDE $SrO \cdot HfO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
273	-0.01
473	0.10
673	0.28
723	0.35
923	0.54
1073	0.62
1273	0.81
1333	0.90
1473	1.00

* No figure given.

FIGURE AND TABLE NO. 117R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF CALCIUM IRON OXIDE $CaO \cdot Fe_2O_3$



PROVISIONAL VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

T	$\Delta L/L_0$	α
293	0.000	11.4
400	0.122	11.6
500	0.239	11.8
600	0.358	12.0
700	0.480	12.2
800	0.603	12.5
900	0.730	12.7
1000	0.858	13.0
1100	0.989	13.2
1200	1.123	13.5
1300	1.259	13.8

REMARKS

The provisional values are considered accurate to within ±10% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.325 + 1.080 \times 10^{-3} T + 9.164 \times 10^{-8} T^2 + 1.135 \times 10^{-11} T^3$$

The tabulated values for the coefficient of thermal expansion are based primarily on the experimental data and are considered accurate to about ±10%.

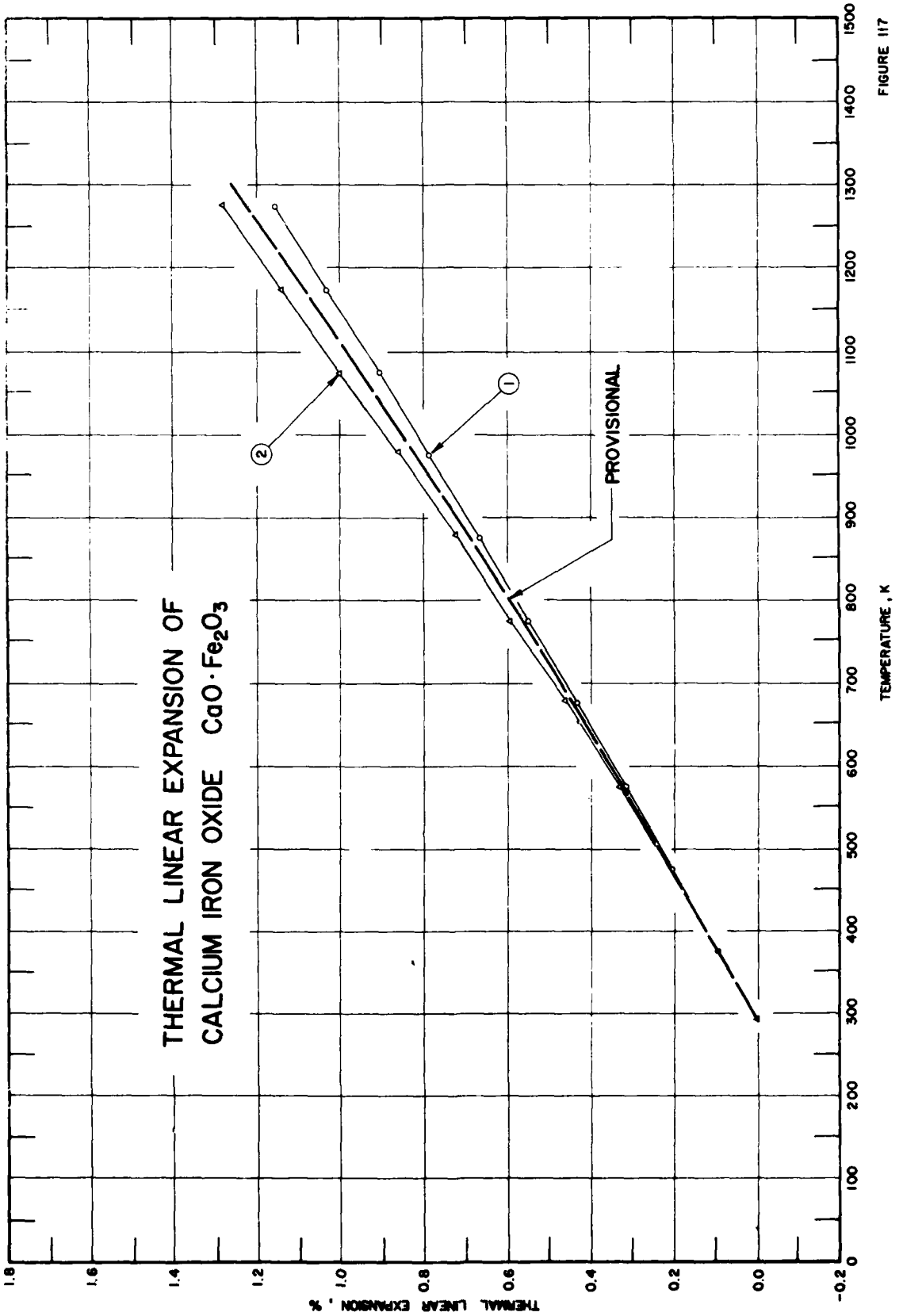

THERMAL LINEAR EXPANSION OF
CALCIUM IRON OXIDE CaO·Fe2O3
PROVISIONAL
1
2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 117

SPECIFICATION TABLE 117. THERMAL LINEAR EXPANSION OF CALCIUM IRON OXIDE $CaO \cdot Fe_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	122	Rigby, G.R. and Green, A.T.	1943	L	373-1473		The correct proportion of rouge and lime made into bar with the addition of 2% to boric acid and heated at 1180 C for 2 hr, powdered, rebonded and reheated to 1150-1180 C; zero-point correction 0.096%.
2	976	Kanclir, E. and Ambruz, V.	1964	L	293-1273		Specimen made from 25.99 CaO and 74.01 Fe_2O_3; data on coefficient of linear also reported.

DATA TABLE 117. THERMAL LINEAR EXPANSION OF CALCIUM IRON OXIDE $CaO \cdot Fe_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 2 (cont.)	
373	0.096	1173	1.032	573	0.33
473	0.205	1273	1.158	673	0.46
573	0.319			773	0.59
673	0.433	CURVE 2		873	0.72
773	0.550			973	0.86
873	0.667	293	0.00	1073	1.00
973	0.786	373	0.09*	1173	1.14
1073	0.908	473	0.21*	1273	1.28

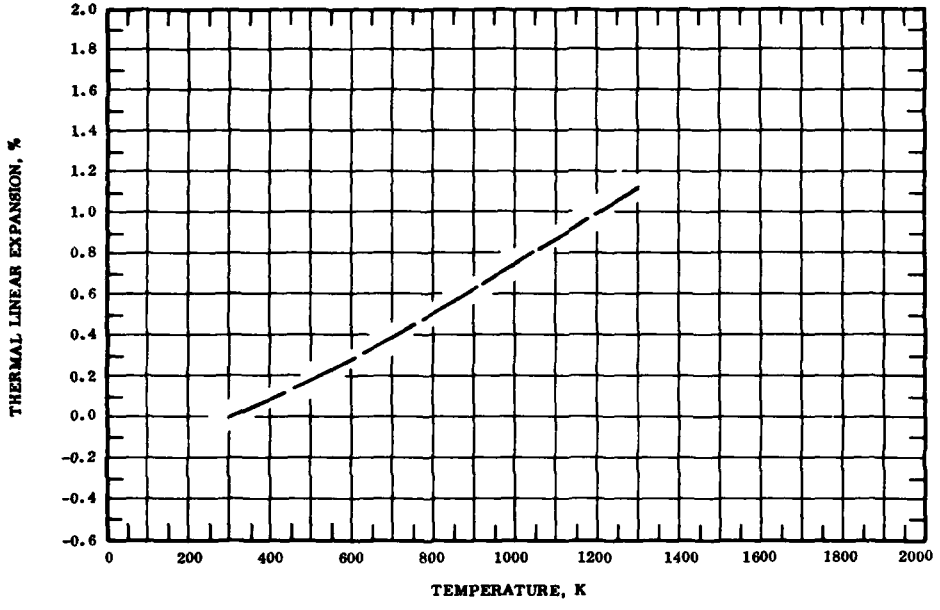
DATA TABLE 117. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CALCIUM IRON OXIDE $CaO \cdot Fe_2O_3$

[Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\ K^{-1}$]

T	α	T	α
CURVE 2*		CURVE 2 (cont.)*	
373	11.7	1073	14.1
473	12.2	1173	14.4
573	12.5	1273	14.6
673	12.9		
773	13.2		
873	13.5		
973	13.8		

* Not shown in figure.

FIGURE AND TABLE NO. 118R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF CALCIUM IRON OXIDE $2CaO \cdot Fe_2O_3$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	9.0
400	0.097	9.4
500	0.193	9.7
600	0.292	10.1
700	0.395	10.5
800	0.502	10.9
900	0.614	11.4
1000	0.731	11.9
1100	0.852	12.4
1200	0.979	12.9
1300	1.111	13.5

REMARKS

The provisional values are considered accurate to within ±10% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.253 + 8.214 \times 10^{-4} T + 1.198 \times 10^{-7} T^2 + 4.289 \times 10^{-11} T^3$$

The tabulated values for the coefficient of thermal expansion are based on both the experimental data and the values obtained by differentiating the above equation. These values are considered accurate to about ±7%.

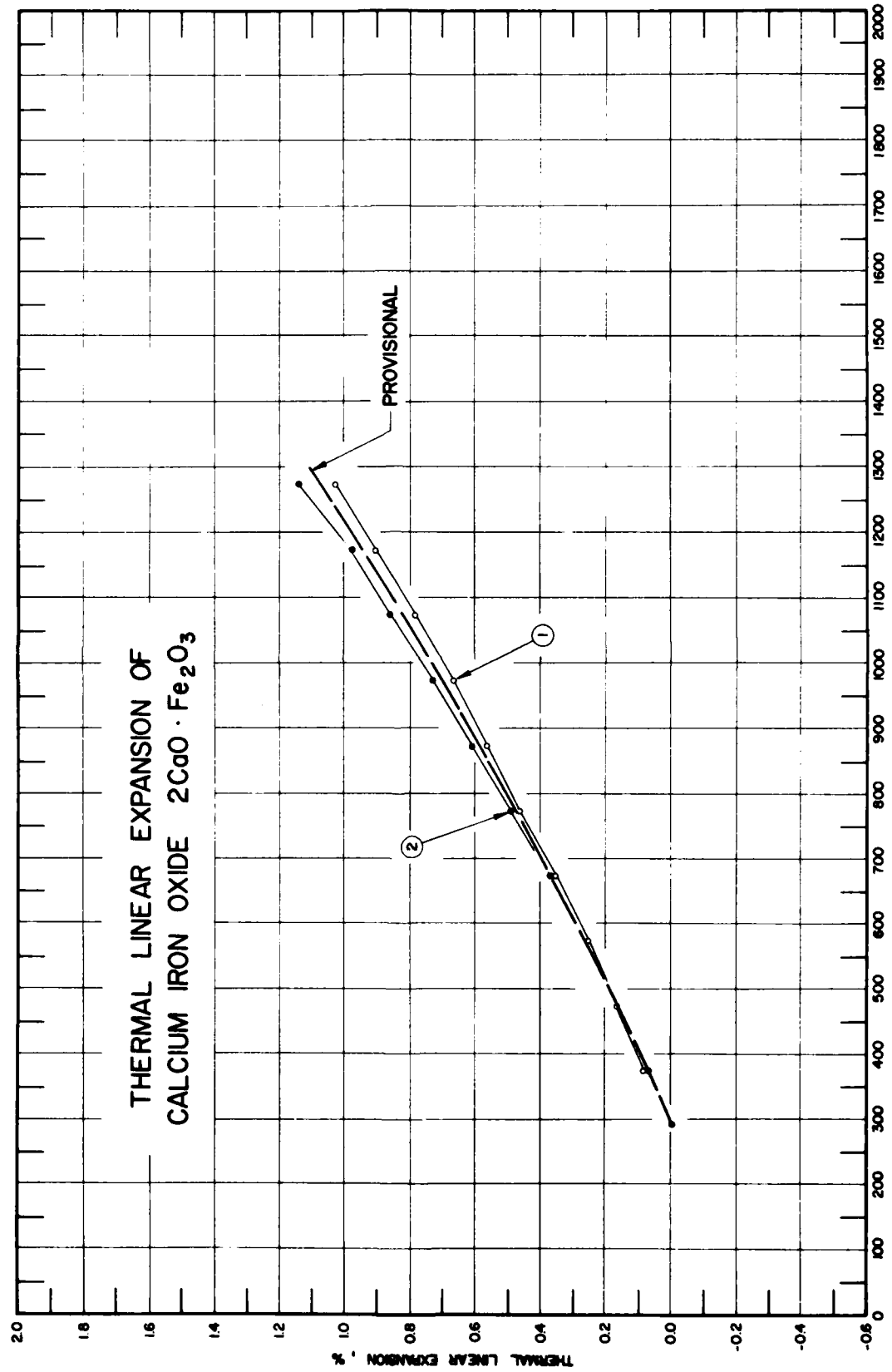

THERMAL LINEAR EXPANSION OF
CALCIUM IRON OXIDE 2CaO · Fe2O3
PROVISIONAL
1
2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 118

SPECIFICATION TABLE 118. THERMAL LINEAR EXPANSION OF CALCIUM IRON OXIDE $2CaO \cdot Fe_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	122	Rigby, G.R. and Green, A.T.	1943	L	373-1473		Specimen was made by heating the appropriate proportions of lime and rough together with 2% of boric acid to 1200 C for eight hr, powdered, rebonded and heated to 1250-1300 C for a further two hr; zero-point correction 0.081%.
2	976	Kanclir, E. and Ambruz, V.	1964	L	293-1277		Specimen made from 41.29 CaO and 58.71 Fe_2O_3; data on coefficient of linear expansion also reported.

DATA TABLE 118. THERMAL LINEAR EXPANSION OF CALCIUM IRON OXIDE $2CaO \cdot Fe_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 2		CURVE 2 (cont.)	
373	0.081	973	0.669	293	0.00	873	0.61
473	0.166	1073	0.785	373	0.07	973	0.73
573	0.258	1173	0.903	473	0.16*	1073	0.86
673	0.358	1273	1.032	573	0.26*	1173	0.99
773	0.464	1373	1.036	673	0.37	1273	1.14
873	0.564	1473	1.251	773	0.49		

DATA TABLE 118. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CALCIUM IRON OXIDE $2CaO \cdot Fe_2O_3$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α
CURVE 2*		CURVE 2 (cont.)*	
373	8.9	873	11.9
473	9.6	973	12.4
573	10.7	1073	13.1
673	12.2	1173	13.6
773	11.9	1273	14.1

* Not shown in figure.

SPECIFICATION TABLE 119. THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM IRON OXIDE $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	122	Rigby, G.R. and Green, A.T.	1943	L	373-1473		Specimen prepared from lime, aluminum hydroxide and rouge with the addition of 2% of boric acid as mineralizer; heated at 1473 K for 8 hr; heated twice to incipient fusion; the specimen being pulverized and rebonded after each treatment; zero-point correction of 0.063% determined by graphical extrapolation.

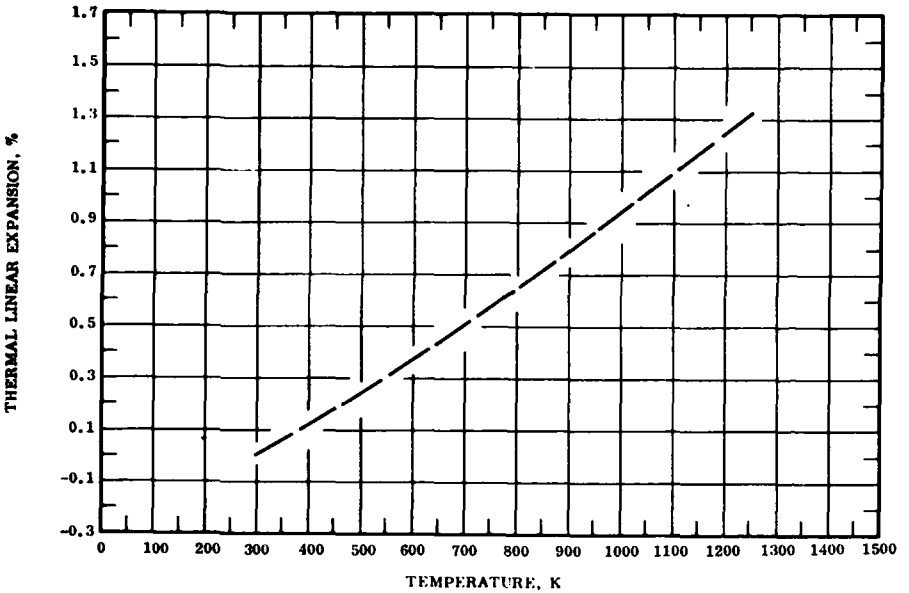
DATA TABLE 119. THERMAL LINEAR EXPANSION OF CALCIUM ALUMINUM IRON OXIDE $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
373	0.063
473	0.142
573	0.239
673	0.339
773	0.439
873	0.526
973	0.623
1073	0.731
1173	0.850
1273	0.971

* No figure given.

FIGURE AND TABLE NO. 120R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF MAGNESIUM IRON OXIDE MgO · 2FeO



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	11.2
400	0.124	11.9
500	0.246	12.5
600	0.373	13.1
700	0.507	13.7
800	0.646	14.2
900	0.791	14.7
1000	0.941	15.2
1100	1.096	15.7
1200	1.256	16.2
1250	1.338	16.4

REMARKS

The provisional values are considered accurate to within ±7% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.300 + 9.262 \times 10^{-4}\, T + 3.475 \times 10^{-7}\, T^2 - 3.217 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ±10%.

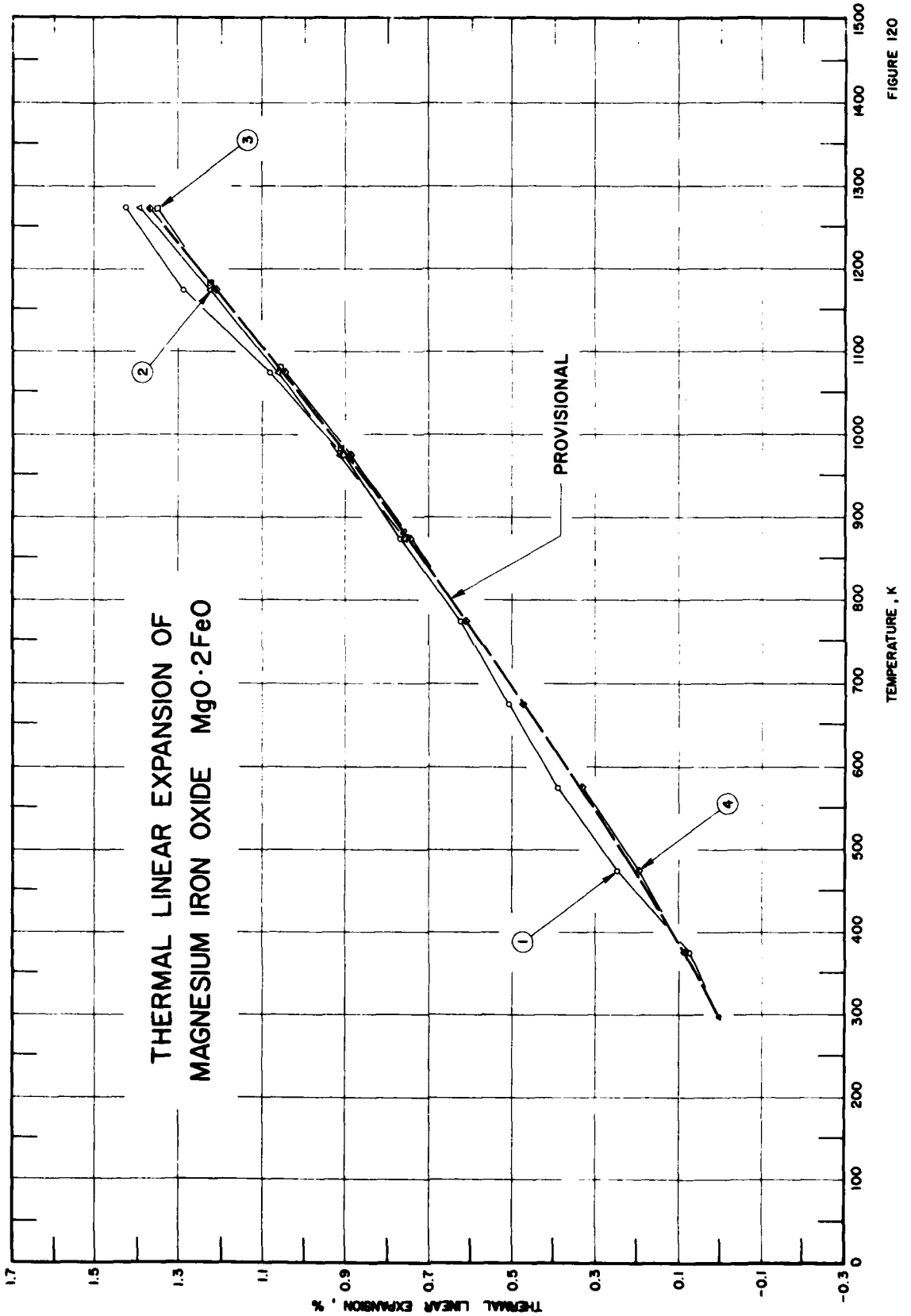

THERMAL LINEAR EXPANSION OF
MAGNESIUM IRON OXIDE MgO·2FeO
PROVISIONAL
1
2
3
4
THERMAL LINEAR EXPANSION , %
1.7
1.5
1.3
1.1
0.9
0.7
0.5
0.3
0.1
-0.1
-0.3
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
TEMPERATURE , K

FIGURE 120

SPECIFICATION TABLE 120. THERMAL LINEAR EXPANSION OF MAGNESIUM IRON OXIDE MgO · 2FeO

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	119	Carter, R.E.	1959	L	298–1273	Magnesio-Wüstite	Specimen prepared by reacting calcined fluorescent-grade $MgCO_3$ and FeO for 16 hr in a platinum boat at 1373 K in a H_2O:H ratio 3.1 atmosphere, ground to -200 mesh, mixed with 2% Carbowax 4000, pressed, then sintered in the same condition as used for calcination; measured with increasing temperature by place specimen in dilatometer, flushing with nitrogen, passing in the H_2O:H atm. and then heating the furnace and measuring the expansion; H_2O:H ratio held at 0.32 up to 833 K, with increasing temperature the ratio raised gradually to 0.88 at 1373 K.
2	119	Carter, R.E.	1959	L	1273–873	Magnesio-Wüstite	The above specimen; expansion measured with decreasing temperature.
3	119	Carter, R.E.	1959	L	298–1273	Magnesio-Wüstite	The above specimen; expansion measured with increasing temperature.
4	119	Carter, R.E.	1959	L	1273–373	Magnesio-Wüstite	The above specimen; expansion measured with decreasing temperature.

DATA TABLE 120. THERMAL LINEAR EXPANSION OF MAGNESIUM IRON OXIDE MgO · 2FeO

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
298	0.004
374	0.079
473	0.247
573	0.389
673	0.507
773	0.626
873	0.769
973	0.906
1073	1.080
1173	1.284
1273	1.429

CURVE 2

T	$\Delta L/L_0$
1273	1.398
1173	1.223
1073	1.060
973	0.912
873	0.760

CURVE 3

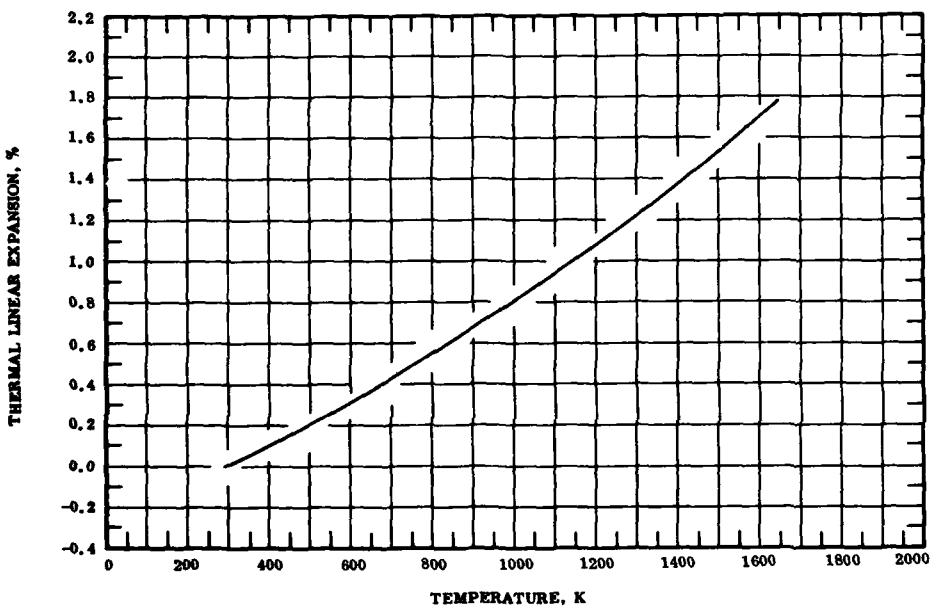
T	$\Delta L/L_0$
298	0.000*
880	0.760
981	0.910
1080	1.060
1181	1.222
1273	1.352

CURVE 4

T	$\Delta L/L_0$
1273	1.370
1173	1.210
1073	1.050
973	0.890
873	0.746
773	0.612
673	0.478
573	0.336
473	0.200
373	0.083

* Not shown in figure.

FIGURE AND TABLE NO. 121R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF MAGNESIUM IRON OXIDE $MgO \cdot Fe_2O_3$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	8.8
400	0.100	9.8
500	0.202	10.6
600	0.311	11.3
700	0.428	11.9
800	0.551	12.6
900	0.679	13.2
1000	0.814	13.7
1100	0.953	14.2
1200	1.097	14.5
1300	1.244	14.9
1400	1.394	15.2
1500	1.548	15.4
1600	1.703	15.6
1650	1.781	15.7

REMARKS

The recommended values are based on the most recent experimental data measured by the x-ray method (Curves 4 and 5). These values are considered accurate to within ±5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.218 + 6.003 \times 10^{-4} T + 5.256 \times 10^{-7} T^2 - 9.404 \times 10^{-11} T^3$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ±5%.

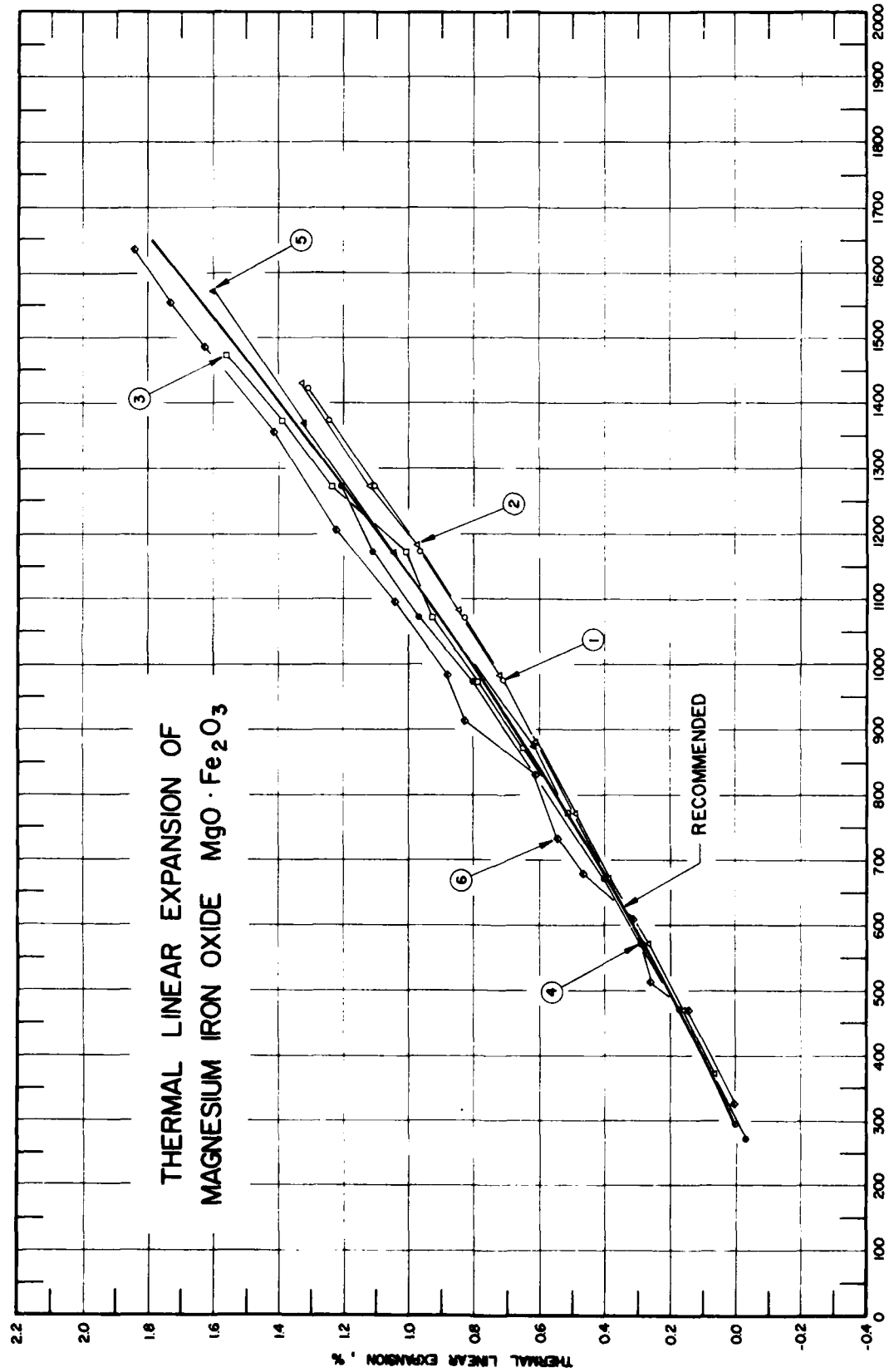

THERMAL LINEAR EXPANSION OF
MAGNESIUM IRON OXIDE MgO · Fe2O3
RECOMMENDED
1
2
3
4
5
6
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 121

SPECIFICATION TABLE 121. THERMAL LINEAR EXPANSION OF MAGNESIUM IRON OXIDE $MgO \cdot Fe_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	119	Carter, R.E.	1959	L	298-1424	Magnesium ferrite $MgFe_2O_4$	High purity $MgFe_2O_4$; specimen 1/8 in. in diameter, 2 in. long, with grain size -200 mesh prepared by mixing 5% Carbowax 4000 to 99.7 pure Fe_2O_3 and fluorescent-grade $MgCO_3$, damp extruded into rod 1/8 in. in diameter, dried, and sintered at 1673 C in pure oxygen.
2	119	Carter, R.E.	1959	L	1430-373	Magnesium ferrite $MgFe_2O_4$	The above specimen; expansion measured with decreasing temperature.
3	97	Rigby, G.R., Lovell, G.H.B., and Green, A.T.	1943		373-1473	Magnesio-ferrite	Equivalent amounts of MgO, Fe_2O_3 and boric acid made into bar, heated at 1200 C for 2 hr, crushed, reheated until homogeneous and boric acid removed; zero-point correction is 0.02%.
4	977	Arkharov, V.I., Bogoslovskii, V.N., and Kuznetsov, E.N.	1972	X	273-1274	Magnesium ferrite	Specimen heated in mixture of CO and CO_2; x-ray photographs taken during isothermal holding with both heating and cooling of specimen; FeK radiation used; lattice parameter measured; 8.339 kX reported at 273 K.
5	673	Kapralik, I.	1969	X	293-1573	$MgFe_2O_4$	Cubic spinel $MgFe_2O_4$; synthesized from Fe_2O_3 and $MgCO_3$; lattice constant reported at 293 K is 8.3716 Å.
6	974	Vishnevskii, I.I. and Alapin, B.G.	1970	X	293-1637	$MgFe_2O_4$	Refractory crystalline specimen; lattice parameter measured, 8.3492 Å reported at room temperature; data reported for heating and cooling; lattice parameter reported at 293 K is 8.379 Å.

DATA TABLE 121. THERMAL LINEAR EXPANSION OF MAGNESIUM IRON OXIDE $MgO \cdot Fe_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.000
975	0.716
1073	0.830
1174	0.968
1273	1.109
1373	1.242
1424	1.316
CURVE 2	
1430	1.332
1375	1.256*
1273	1.122
1184	0.979

T	$\Delta L/L_0$
CURVE 2 (cont.)	
1083	0.844
981	0.726
882	0.611
773	0.489
673	0.384
573	0.267
473	0.160
373	0.062
CURVE 3	
373	0.07*
473	0.16*
573	0.26*

T	$\Delta L/L_0$
CURVE 3 (cont.)	
673	0.38*
773	0.51
873	0.65
973	0.79
1073	0.93
1173	1.09
1273	1.24
1373	1.39
1473	1.56
CURVE 4	
273	-0.031
293	0.000*

T	$\Delta L/L_0$
CURVE 4 (cont.)	
373	0.062*
473	0.177
573	0.288
673	0.400
773	0.503*
873	0.628*
973	0.802
1073	0.977
1173	1.116
1273	1.203
1274	1.229*

T	$\Delta L/L_0$
CURVE 5	
293	0.000*
579	0.293*
876	0.620
1173	1.048
1370	1.323
1573	1.605
CURVE 6	
293	0.000*
327	0.000
472	0.150
516	0.260
611	0.310

T	$\Delta L/L_0$
CURVE 6 (cont.)	
680	0.464
735	0.543
831	0.613
914	0.828
983	0.881
1097	1.044
1208	1.221
1355	1.420
1486	1.624
1557	1.733
1637	1.841

* Not shown in figure.

SPECIFICATION TABLE 122. THERMAL LINEAR EXPANSION OF STRONTIUM LEAD OXIDE $SrO \cdot PbO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	978	White, W. B. and Keester, K. L.	1969	X	293–706	$SrPbO_3$	Specimen prepared from stoichiometric mixture of PbO_2 and $Sr(OH)_2 \cdot 8H_2O$; ground under acetone to finely homogeneous powder, discs from predensified material sintered in additional $SrPbO_3$ powder; expansion measured along a-axis of orthorhombic structure.
2*	978	White, W. B. and Keester, K. L.	1969	X	293–705	$SrPbO_3$	The above specimen, expansion measured along b-axis of orthorhombic structure.
3*	978	White, W. B. and Keester, K. L.	1969	X	293–705	$SrPbO_3$	The above specimen, expansion measured along c-axis of orthorhombic structure.
4*	978	White, W. B. and Keester, K. L.	1969	X	774–851	$SrPbO_3$	The above specimen, expansion measured along a-axis of tetrahedral structure after transformation at ~ 713 K.
5*	978	White, W. B. and Keester, K. L.	1969	X	774–849	$SrPbO_3$	The above specimen, expansion measured along c-axis of tetrahedral structure.

DATA TABLE 122. THERMAL LINEAR EXPANSION OF STRONTIUM LEAD OXIDE $SrO \cdot PbO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
330	0.138
386	0.176
412	0.193
438	0.323
454	0.311
489	0.415
670	0.772
670	0.825
696	0.898
706	0.951

T	$\Delta L/L_0$
CURVE 2*	
293	0.000
330	0.019
383	0.114
411	0.071
435	0.019
453	0.076
485	0.112
491	0.024
669	0.071
669	0.218
695	0.123
705	0.475

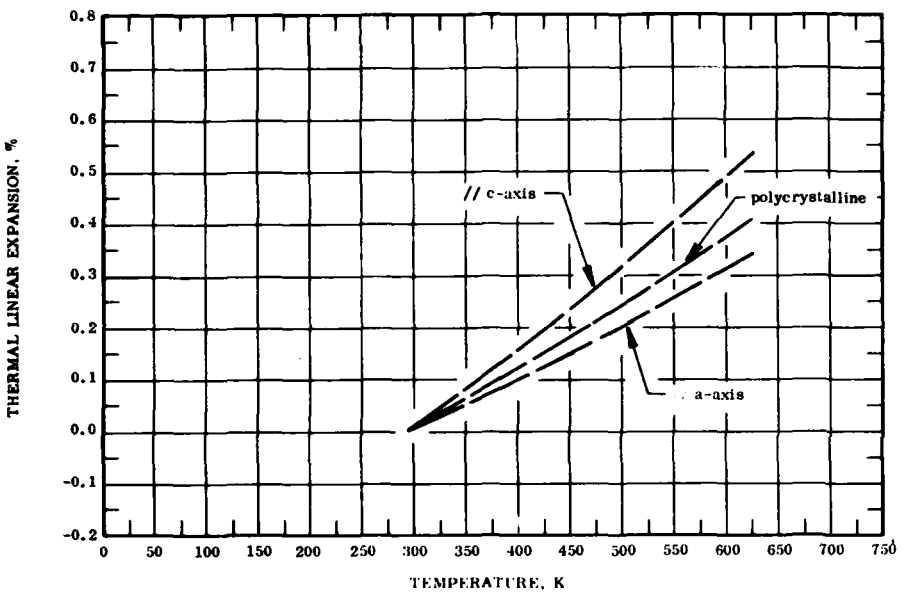
T	$\Delta L/L_0$
CURVE 3*	
293	0.000
331	0.115
385	0.072
412	0.137
437	0.189
453	0.156
484	0.261
491	0.261
491	0.319
670	0.381
670	0.481
696	0.402
705	0.402

T	$\Delta L/L_0$
CURVE 4*	
774	0.1823
806	0.1828
816	0.1836
836	0.1916
840	0.1945
848	0.1875
851	0.1857

T	$\Delta L/L_0$
CURVE 5*	
774	0.2165
805	0.2190
814	0.2209
834	0.2229
835	0.2146
843	0.2135
847	0.2226
849	0.2206

* No figure given.

FIGURE AND TABLE NO. 123R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF CALCIUM MOLYBDENUM OXIDE $CaO \cdot MoO_3$



PROVISIONAL VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	10.9
350	0.052	0.084	0.063	11.3
400	0.100	0.160	0.120	11.6
450	0.149	0.238	0.179	12.0
500	0.201	0.319	0.240	12.5
550	0.255	0.403	0.304	13.0
600	0.311	0.490	0.371	13.6
625	0.340	0.535	0.405	14.0

REMARKS

The provisional values for the polycrystalline sample are calculated directly from the tabulated axial values. These values are considered accurate to within ±10% and are represented approximately by the following eqaution:

// a-axis: $\Delta L/L_0 = -0.253 + 8.505 \times 10^{-4} T - 5.414 \times 10^{-8} T^2 + 3.378 \times 10^{-10} T^3$

// c-axis: $\Delta L/L_0 = -0.425 + 1.494 \times 10^{-3} T - 3.425 \times 10^{-7} T^2 + 6.563 \times 10^{-10} T^3$

polycrystalline: $\Delta L/L_0 = -3.055 \times 10^{-1} + 1.032 \times 10^{-3} T + -7.773 \times 10^{-8} T^2 + 3.943 \times 10^{-10} T^3$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ±10%.

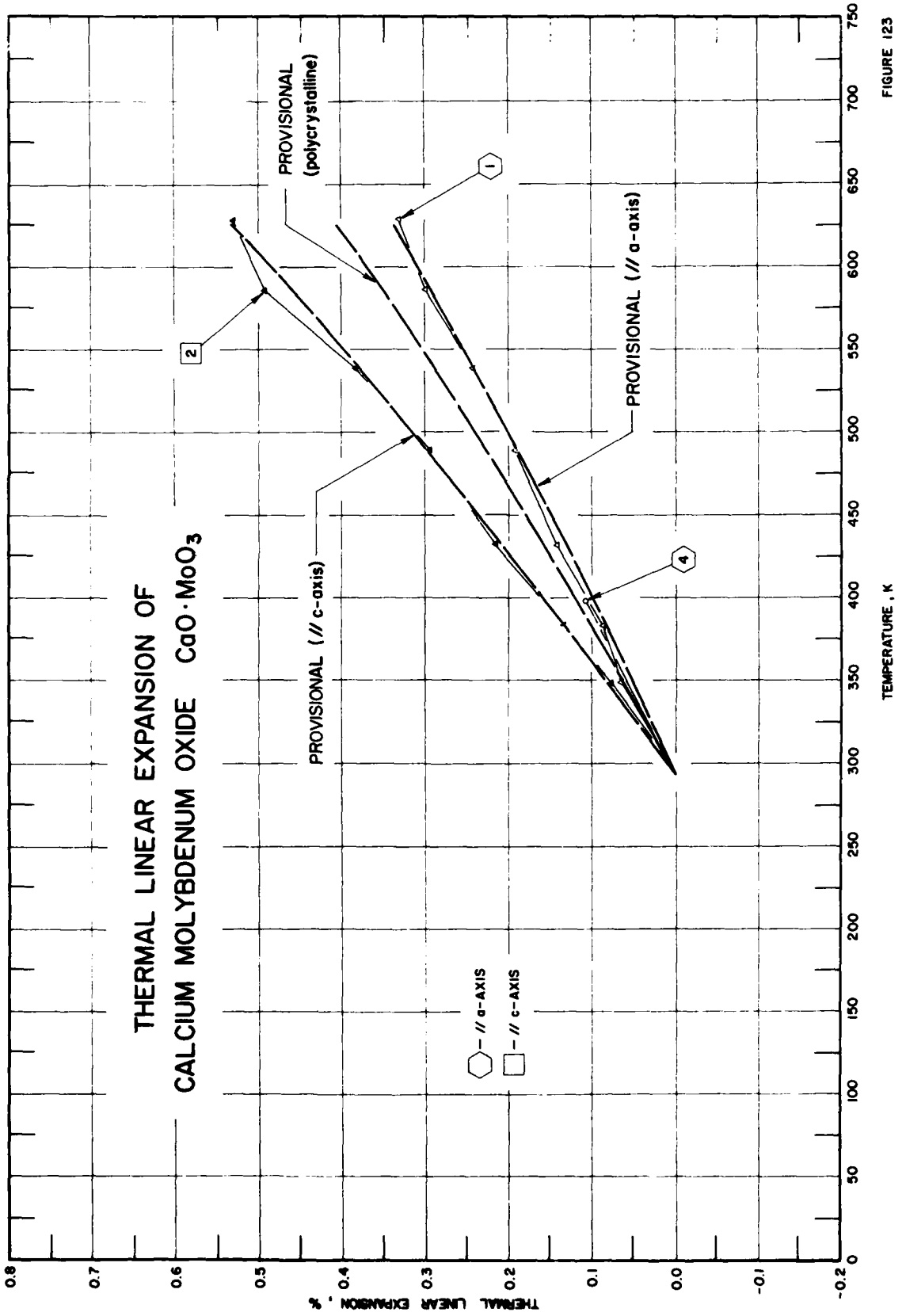

THERMAL LINEAR EXPANSION OF
CALCIUM MOLYBDENUM OXIDE CaO·MoO3
PROVISIONAL (polycrystalline)
PROVISIONAL (// c-axis)
PROVISIONAL (// a-axis)
1
2
4
// a-AXIS
// c-AXIS
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750

FIGURE 123

SPECIFICATION TABLE 123. THERMAL LINEAR EXPANSION OF CALCIUM MOLYBDENUM OXIDE $CaO \cdot MoO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1028	Desphande, V.T. and Suryanarayana, V.T.	1969	X	306-628		Synthetic single crystal supplied by National Bureau of Standards; crushed to fire powder form; expansion measured along a-axis; 5.2266 Å reported at 306 K.
2	1028	Desphande, V.T. and Suryanarayana, V.T.	1969	X	306-628		The above specimen; expansion measured along c-axis; 11.4352 Å reported.
3	923	Morozov, A.M. and Selezneva, A.M.	1969	I	293, 398		Pure single crystal of scheelite type; grown by pulling from melt; expansion measured along c-axis.
4	923	Morozov, A.M. and Selezneva, A.M.	1969	I	293, 398		The above specimen; expansion measured perpendicular to c-axis.

DATA TABLE 123. THERMAL LINEAR EXPANSION OF CALCIUM MOLYBDENUM OXIDE $CaO \cdot MoO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
306	0.015
348	0.065
383	0.088
431	0.142
488	0.191
538	0.243
585	0.300
628	0.331

T	$\Delta L/L_0$
CURVE 2	
306	0.018*
348	0.078
383	0.133
431	0.215
488	0.295
538	0.383
585	0.492
628	0.530

T	$\Delta L/L_0$
CURVE 3	
293	0.000
398	0.183
CURVE 4	
293	0.000*
398	0.109

* Not shown in figure.

SPECIFICATION TABLE 124. THERMAL LINEAR EXPANSION OF GADOLINIUM MOLYBDENUM OXIDE $Gd_2O_3 \cdot 3MoO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	965	Newnham, R.E., McKinstry, H.A., Gregg, C.W., and Stitt, W.R.	1969	X	296-410	$Gd_2(MoO_4)_3$	Polycrystalline specimen prepared by solid state reaction of the oxides; orthorhombic cell; CuKα radiation used; expansion measured along a-direction; 10.390 Å reported at 296 K.
2*	965	Newnham, R.E., et al.	1969	X	296-410	$Gd_2(MoO_4)_3$	The above specimen; expansion measured along b-direction; 10.417 Å reported at 296 K.
3*	965	Newnham, R.E., et al.	1969	X	296-410	$Gd_2(MoO_4)_3$	The above specimen; expansion measured along c-direction; 10.696 Å reported at 296 K.

DATA TABLE 124. THERMAL LINEAR EXPANSION OF GADOLINIUM MOLYBDENUM OXIDE $Gd_2O_3 \cdot 3MoO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
296	0.009
383	0.192
410	0.250
CURVE 2*	
296	0.000
383	0.125
410	0.173
CURVE 3*	
296	0.000
383	-0.019
410	-0.103

* No figure given.

SPECIFICATION TABLE 125. THERMAL LINEAR EXPANSION OF SODIUM LANTHANUM MOLYBDENUM OXIDE $Na_2O \cdot La_2O_3 \cdot 4MoO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	923	Morozov, A.M. and Selezneva, A.M.	1966	I	293, 398	$LaN_2(MoO_4)_2$	Pure single crystal of scheelite type grown by pulling from melt; expansion measured parallel to c-axis.
2*	923	Morozov, A.M. and Selezneva, A.M.	1966	I	293, 398	$LaN_2(MoO_4)_2$	The above specimen; expansion measured perpendicular to c-axis.

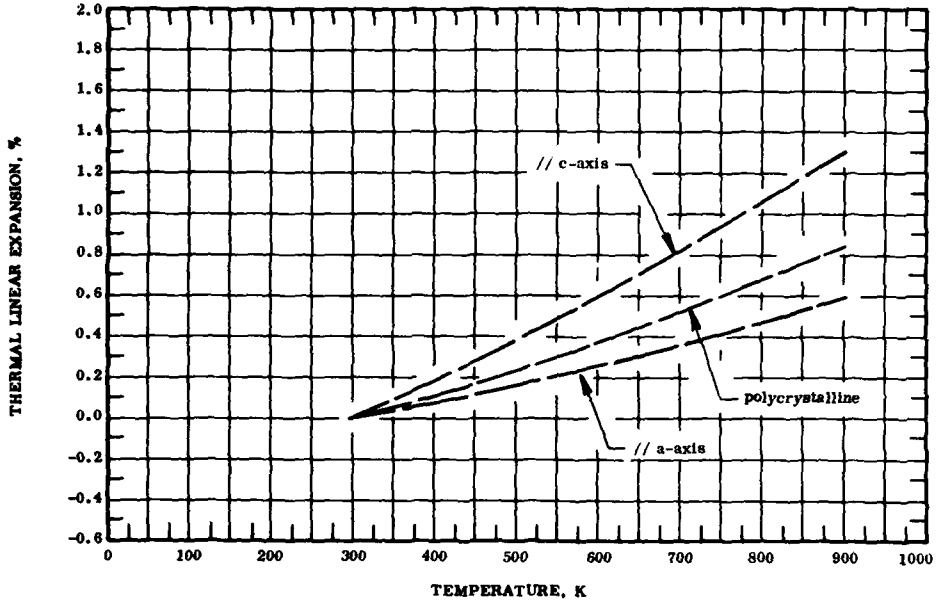
DATA TABLE 125. THERMAL LINEAR EXPANSION OF SODIUM LANTHANUM MOLYBDENUM OXIDE $Na_2O \cdot La_2O_3 \cdot 4MoO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
398	0.228
CURVE 2*	
293	0.000
398	0.102

* No figure given.

FIGURE AND TABLE NO. 126R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF STRONTIUM MOLYBDENUM OXIDE $SrO \cdot MoO_3$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	10.1
350	0.042	0.096	0.060	10.9
400	0.080	0.188	0.116	11.6
450	0.121	0.286	0.176	12.2
500	0.163	0.389	0.238	12.8
550	0.208	0.496	0.304	13.4
600	0.255	0.607	0.372	13.9
650	0.304	0.722	0.443	14.4
700	0.356	0.838	0.517	14.9
750	0.411	0.955	0.592	15.3
800	0.468	1.074	0.670	15.7
850	0.529	1.191	0.750	16.1
900	0.592	1.308	0.831	16.6

REMARKS

The provisional values for the polycrystalline sample are calculated directly from the tabulated axial values. These values are considered accurate to within ±1.0% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.188 + 5.855 \times 10^{-4}\ T + 1.388 \times 10^{-7}\ T^2 + 1.940 \times 10^{-10}\ T^3$

// c-axis: $\Delta L/L_0 = -0.312 + 4.348 \times 10^{-4}\ T + 2.453 \times 10^{-6}\ T^2 - 1.040 \times 10^{-9}\ T^3$

polycrystalline: $\Delta L/L_0 = -0.227 + 5.212 \times 10^{-4}\ T + 9.427 \times 10^{-7}\ T^2 - 2.283 \times 10^{-10}\ T^3$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ±10%.

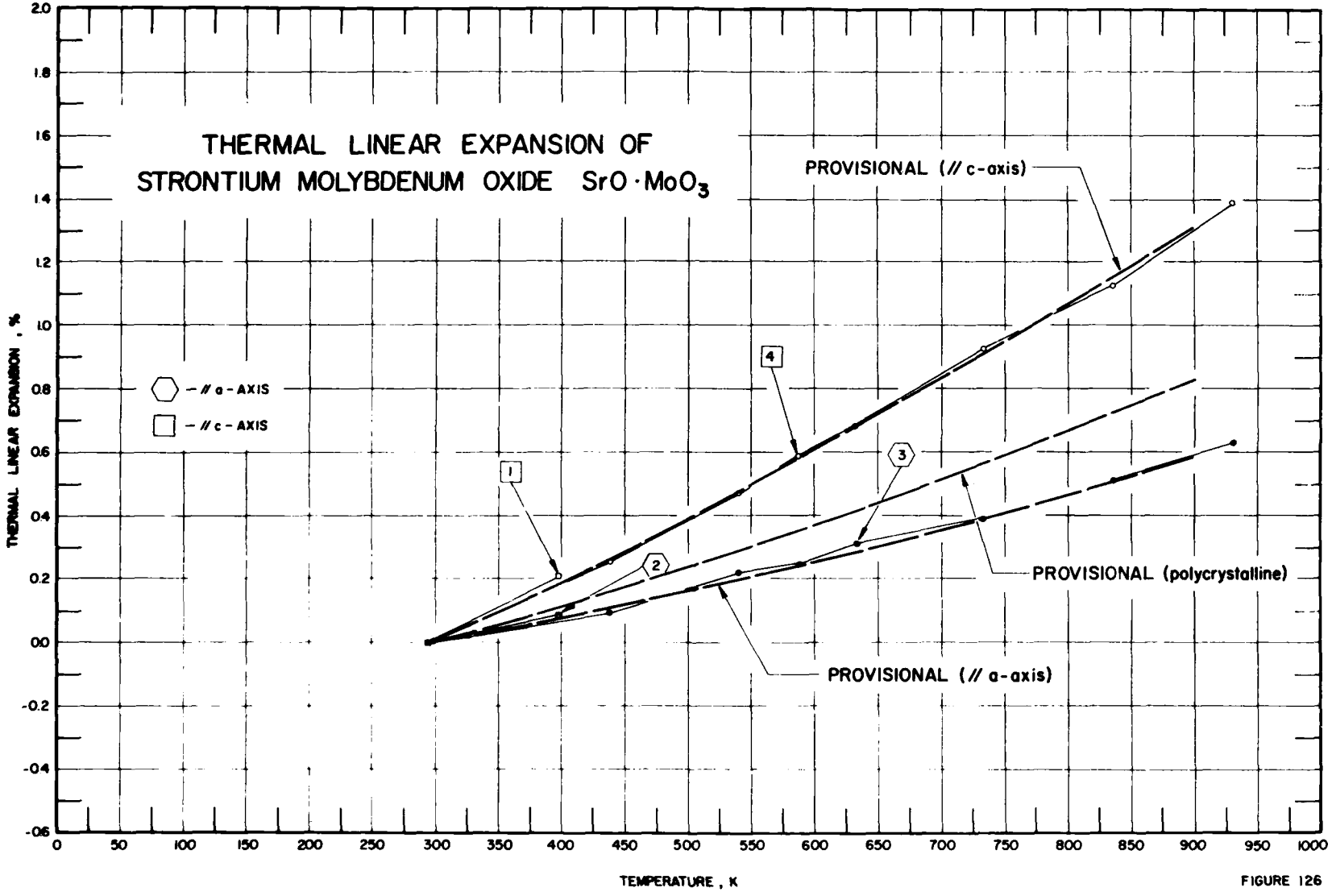

THERMAL LINEAR EXPANSION OF
STRONTIUM MOLYBDENUM OXIDE SrO·MoO3
PROVISIONAL (// c-axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// a-axis)
⬡ – // a-AXIS
□ – // c-AXIS
1
2
3
4
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 126

SPECIFICATION TABLE 126. THERMAL LINEAR EXPANSION OF STRONTIUM MOLYBDENUM OXIDE $SrO \cdot MoO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	923	Morozov, A.M. and Selezneva, A.M.	1966	I	293, 398	$SrMoO_4$	Pure single crystal of scheelite type grown by pulling from melt; expansion measured parallel to c-axis.
2	923	Morozov, A.M. and Selezneva, A.M.	1966	I	293, 398	$SrMoO_4$	The above specimen; expansion measured perpendicular to c-axis.
3	966	Deshpande, V.T. and Suryanarayana, S.V.	1972	X	299-931	$SrMoO_4$	Small chip crystals crushed to fine powder form; put in thin walled quartz capillary tube of about 0.5 mm inner diameter; lattice parameter measured along a-axis; 5.3964 Å reported at 299 K.
4	966	Deshpande, V.T. and Suryanarayana, S.V.	1972	X	299-931	$SrMoO_4$	The above specimen; lattice parameter measured along c-axis; 12.0232 Å reported at 299 K.

DATA TABLE 126. THERMAL LINEAR EXPANSION OF STRONTIUM MOLYBDENUM OXIDE $SrO \cdot MoO_3$

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %)

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 3		CURVE 4	
293	0.000	299	0.004	299	0.011*
398	0.205	438	0.098	438	0.259
CURVE 2		540	0.220	540	0.470
		588	0.250	588	0.593
293	0.000*	634	0.319	634	0.685
398	0.092	734	0.393	734	0.927
		836	0.515	836	1.125
		931	0.630	931	1.397

* Not shown in figure.

SPECIFICATION TABLE 127. THERMAL LINEAR EXPANSION OF DYSPROSIUM NIOBIUM OXIDE $Dy_2O_3 \cdot Nb_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	248	Ploetz, G. L., Muccigrosso, A. T., Osika, L. M., and Jacoby, W. R.	1960	L	293-1273	$DyNbO_4$	58.3 Dy_2O_3, 41.7 Nb_2O_5; prepared by wet ball milling with flint pebbles for 2 hr, dry pressed at 20 000 psi with 2 weight percent soluble wax emulsion into 0.5 in. diameter, 1 in. long pellets, and fired in air atmosphere; m.p. 1950 C; density 5.493 g cm^{-3}.

DATA TABLE 127. THERMAL LINEAR EXPANSION OF DYSPROSIUM NIOBIUM OXIDE $Dy_2O_3 \cdot Nb_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡	
373	0.055	973	0.592
473	0.132	1072	0.691
573	0.216	1173	0.792
673	0.305	1273	0.893
773	0.398		
873	0.494		

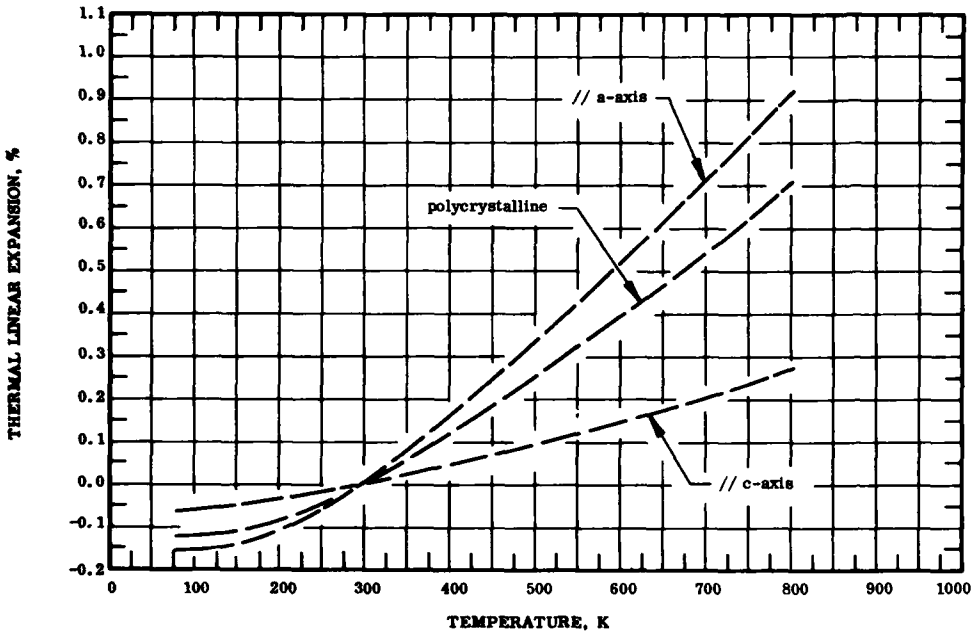
DATA TABLE 127. COEFFICIENT OF THERMAL LINEAR EXPANSION OF DYSPROSIUM NIOBIUM OXIDE $Dy_2O_3 \cdot Nb_2O_5$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡	
373	7.25	1072	10.02
473	8.23	1173	10.10
573	8.56	1273	10.10
673	9.12		
773	9.51		
873	9.70		
973	9.87		

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 128R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF LITHIUM NIOBIUM OXIDE $Li_2O \cdot Nb_2O_5$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
75	-0.154	-0.055	-0.118	1.2
125	-0.149	-0.056	-0.118	1.5
150	-0.140	-0.052	-0.111	2.6
175	-0.127	-0.047	-0.101	5.1
200	-0.110	-0.040	-0.087	6.9
225	-0.087	-0.031	-0.067	8.3
250	-0.060	-0.020	-0.047	9.5
275	-0.028	-0.009	-0.022	10.5
293	0.000	0.000	0.000	11.1
350	0.083	0.022	0.061	11.9
400	0.166	0.044	0.124	12.4
450	0.250	0.066	0.189	12.8
500	0.336	0.090	0.255	13.3
550	0.425	0.114	0.323	13.8
600	0.517	0.141	0.393	14.3
650	0.612	0.169	0.463	14.9
700	0.711	0.200	0.540	15.4
750	0.813	0.233	0.617	16.0
800	0.918	0.268	0.703	16.7

REMARKS

The provisional values for the axial thermal expansion are based on the data for samples of trigonal structure. The values for the polycrystalline sample are calculated from the tabulated axial values. These values are considered accurate to within ± 10% with the exception of the parallel to c-axis values which are accurate to ± 25% above 600 K. These values are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.139 - 3.599 \times 10^{-4} T + 1.847 \times 10^{-6} T^2 + 3.437 \times 10^{-9} T^3$ (75-293 K)

$\Delta L/L_0 = -0.406 + 1.237 \times 10^{-3} T + 4.416 \times 10^{-7} T^2 + 9.908 \times 10^{-11} T^3$ (293-800 K)

// c-axis: $\Delta L/L_0 = -0.032 - 5.061 \times 10^{-4} T + 2.863 \times 10^{-6} T^2 - 2.615 \times 10^{-9} T^3$ (75-293 K)

$\Delta L/L_0 = -0.129 + 4.897 \times 10^{-4} T - 2.907 \times 10^{-7} T^2 + 3.753 \times 10^{-10} T^3$ (293-800 K)

polycrystalline: $\Delta L/L_0 = -0.088 - 6.672 \times 10^{-4} T + 3.543 \times 10^{-6} T^2 - 8.440 \times 10^{-10} T^3$ (75-293 K)

$\Delta L/L_0 = -0.310 + 9.674 \times 10^{-4} T + 2.381 \times 10^{-7} T^2 + 1.663 \times 10^{-10} T^3$ (293-800 K)

The tabulated values for the coefficient of thermal expansion are derived from both the experimental data and the values obtained by differentiating the above equations. These values are considered accurate to about ± 15%.

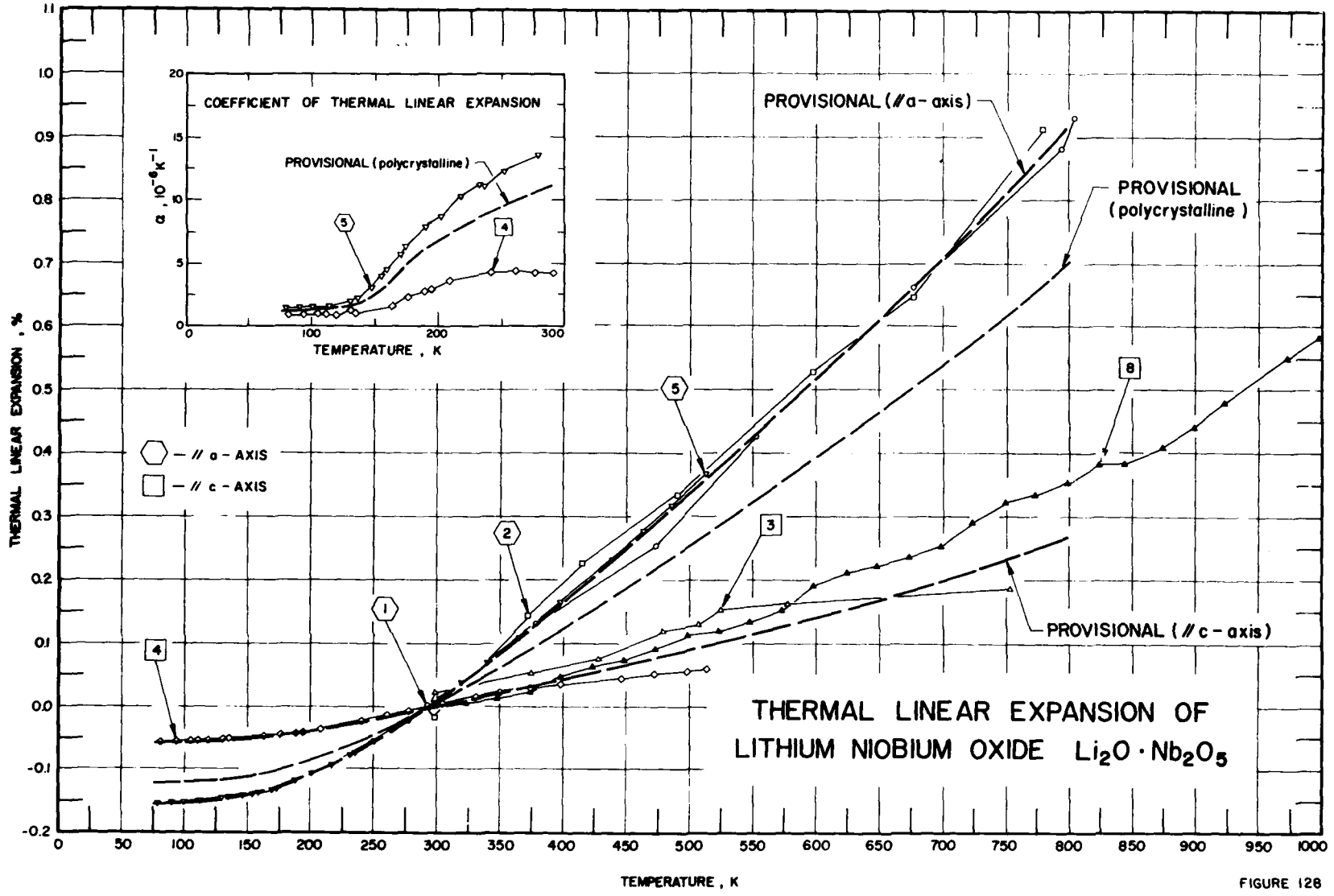

COEFFICIENT OF THERMAL LINEAR EXPANSION
PROVISIONAL (polycrystalline)
α , $10^{-6}K^{-1}$
TEMPERATURE , K
PROVISIONAL (// a - axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// c - axis)
// a - AXIS
// c - AXIS
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
THERMAL LINEAR EXPANSION OF
LITHIUM NIOBIUM OXIDE $Li_2O \cdot Nb_2O_5$

FIGURE 128

SPECIFICATION TABLE 128. THERMAL LINEAR EXPANSION OF LITHIUM NIOBIUM OXIDE $Li_2O \cdot Nb_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	195	Kim, Y.S. and Smith, R.T.	1969	X	293-804		Single crystal, ferroelectric specimen; prepared by Czychralski technique; thin, parallel-side specimen plates of approximate dimensions 0.05 x 0.25 x 0.6 cm; prepared from the electrically poled crystal boules; iron (Kα) radiation used, at 298 K lattice spacing 1.287 Å on plane (22.0); plate normal aligned with the crystallographic x-axis.
2	195	Kim, Y.S. and Smith, R.T.	1969	X	293-779		Similar to the above specimen; at 298 K lattice spacing 1.489 Å on plane (03.0); plate normal aligned with the crystallographic y-axis.
3	195	Kim, Y.S. and Smith, R.T.	1969	X	293-754		Similar to the above specimen; at 298 K lattice spacing 1.151 Å on plane (00.12); plate normal aligned with the crystallographic z-axis.
4	292	Zhdanova, V.V., Klyuev, V.P., Lemanov, V.V., Smirnov, I.A., and Tikhonov, V.V.	1968	L	81-513		Specimen cut from crystal grown from melt; expansion measured along triogonal axis.
5	292	Zhdanova, V.V., et al.	1968	L	79-513		The above specimen; expansion measured perpendicular to trigonal axis.
6	720	Shapiro, Z.I., Fedulov, S.A., Venertsev, Yu.N., and Rigerman, L.G.	1966	X	273-973		Sinters of $LiNbO_3$ made from mixtures of lithium carbonate (analytical grade) and the pentoxides (purity not less than 98%) by double firing at temperature of 1050 and 1120 C, crystals grown to diameter of 5-8 mm and lengths of 40-50 mm, at 600 C $LiNbO_3$ passes from one frozen-in ferroelectric state to another without appreciable alteration in the shape of the cell; expansion measured along hexagonal a-axis; 5.135 Å reported at 293 K.
7	720	Shapiro, Z.I., et al.	1966	X	273-973		The above specimen; expansion measured along hexagonal c-axis; 13.820 Å reported at 293 K.
8	721	Smolenskii, G.A., Krainik, N.N., Khuchua, N.P., Zhdanova, V.V., and Mylnikova, I.E.	1966	L	293-1443		Single crystals grown by flux method, Li_2CO_3 and LiCl "pro analysi" and Nb_2O_5 of 99% purity were used and a mixture of 5 mole percent Li_2CO_3, 5 mole percent Nb_2O_5, and 90 mole percent LiCl was put in a platinum crucible and heated to 1250-1300 C, furnace cooled at 5 to 7°/hr to 800 C getting crystals of area 1 cm^2; Curie temperature 1140 C; expansion measured along the polar axis (the three fold axis X_3).
9*	721	Smolenskii, G.A., et al.	1966	L	293-1443		Similar to the above except expansion measured perpendicular to the glide plane (X_1).

* Not shown in figure.

DATA TABLE 128. THERMAL LINEAR EXPANSION OF LITHIUM NIOBIUM OXIDE $Li_2O \cdot Nb_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
298	0.002
379	0.131
473	0.254
552	0.429
676	0.665
794	0.883
804	0.932
CURVE 2	
293	0.000
298	-0.017
372	0.144
415	0.226
490	0.333
597	0.529
676	0.648
779	0.914
CURVE 3	
293	0.000
298	0.022
375	0.051
428	0.076
478	0.119
507	0.130
525	0.151
578	0.162
754	0.187
CURVE 4‡	
81	-0.057
93	-0.056
105	-0.054
111	-0.054
118	-0.053
131	-0.052
135	-0.051
163	-0.048
176	-0.045
188	-0.042
194	-0.040
208	-0.036
241	-0.022

T	$\Delta L/L_0$
CURVE 4 (cont.)‡	
261	-0.014
277	-0.007
291	-0.001
305	0.005
331	0.016
350	0.023
374	0.030
399	0.037
446	0.046
472	0.051
498	0.056
513	0.060
CURVE 5‡	
79	-0.155
90	-0.153
100	-0.152
113	-0.150
130	-0.147
136	-0.146
147	-0.143
155	-0.140
159	-0.138
170	-0.133
173	-0.131
189	-0.120
202	-0.109
217	-0.094
232	-0.078
236	-0.074
251	-0.056
278	-0.021
302	0.012
320	0.039
340	0.069
366	0.110
398	0.163
438	0.232
463	0.277
486	0.319
513	0.369
CURVE 6	
287	-0.039
293	0.000*

T	$\Delta L/L_0$
CURVE 6 (cont.)	
573	0.195
765	0.311
820	0.389
840	0.409
852	0.428
862	0.448
872	0.467
883	0.467
891	0.487
902	0.506
924	0.526
973	0.565
CURVE 7	
293	0.000*
570	-0.203
675	-0.289
760	-0.405
823	-0.485
843	-0.463
855	-0.507
865	-0.478
874	-0.478
885	-0.514
899	-0.738
913	-0.753
924	-0.724
974	-0.781
CURVE 8	
293	0.000
298	0.000
323	0.004
348	0.013
373	0.026
398	0.049
423	0.064
448	0.076
473	0.092
498	0.111
523	0.120
548	0.135
573	0.153
598	0.193
623	0.213

T	$\Delta L/L_0$
CURVE 8 (cont.)	
648	0.228
673	0.237
698	0.256
723	0.297
748	0.324
773	0.338
798	0.357
823	0.386
848	0.386
873	0.411
898	0.443
923	0.481
948	0.521
973	0.553
998	0.586
1023	0.616*
1048	0.652*
1073	0.677*
1098	0.707*
1123	0.730*
1148	0.761*
1173	0.773*
1198	0.773*
1223	0.767*
1248	0.750*
1273	0.762*
1298	0.770*
1323	0.770*
1348	0.766*
1373	0.747*
1398	0.721*
1403	0.677*
1423	0.675*
1435	0.679*
CURVE 9*	
293	0.000
298	0.007
323	0.011
348	0.036
373	0.061
385	0.072
398	0.066
423	0.081
448	0.109
473	0.109

T	$\Delta L/L_0$
CURVE 9 (cont.)*	
498	0.130
523	0.151
548	0.175
561	0.193
573	0.227
598	0.257
623	0.290
648	0.321
673	0.330
688	0.330
698	0.361
723	0.409
748	0.460
773	0.474
798	0.498
823	0.552
848	0.569
873	0.617
898	0.670
923	0.673
948	0.703
973	0.738
998	0.786
1023	0.823
1048	0.842
1073	0.881
1098	0.930
1123	0.968
1148	0.978
1173	0.992
1198	1.030
1223	1.048
1248	1.031
1273	1.039
1298	1.059
1323	1.071
1348	1.075
1373	1.075
1398	1.055
1408	1.024
1423	1.028
1432	1.033

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 128. COEFFICIENT OF THERMAL LINEAR EXPANSION OF LITHIUM NIOBIUM OXIDE $Li_2O \cdot Nb_2O_5$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 4‡	
81	0.9
93	1.0
105	1.0
111	1.0
118	0.8
131	1.3
135	1.1
163	1.6
176	2.3
188	2.8
194	3.0
208	3.7
241	4.3
261	4.4
277	4.3
291	4.3
305	4.1*
331	3.9*
350	3.6*
374	3.0*
399	2.3*
446	1.7*
472	1.9*
498	2.1*
513	2.2*
CURVE 5‡	
79	1.4
90	1.5
100	1.5
113	1.6
130	1.9
136	2.2
147	3.1
155	4.0
159	4.5
170	5.7
173	6.3
189	7.9
202	8.7
217	10.3
232	11.2
236	11.1
251	12.3
278	13.6

T	α
CURVE 5 (cont.)‡	
302	14.5*
320	14.9*
340	15.5*
366	16.1*
398	16.8*
438	17.6*
463	18.3*
486	18.5*
513	18.8*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 129. THERMAL LINEAR EXPANSION OF MAGNESIUM NIOBIUM OXIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	19	Durbin, E.A. and Harmon, C.G.	1952	I	298-718	$MgO \cdot Nb_2O_5$	Magnesium niobium oxide; 99.5 pure MgO and 99.9 pure Nb_2O_5 used as starting materials; specimen sintered for 2 hr at 1723 K and cooled in furnace.
2*	19	Durbin, E.A. and Harmon, C.G.	1952	I	298-1048	$2MgO \cdot Nb_2O_5$	Magnesium niobium oxide; 99.5 pure MgO and 99.9 pure Nb_2O_5 starting materials; specimen sintered for 2 hr at 1773 K and cooled in furnace.
3*	19	Durbin, E.A. and Harmon, C.G.	1952	I	298-928	$3MgO \cdot Nb_2O_5$	Magnesium niobium oxide; 99.5 pure MgO and 99.9 pure Nb_2O_5 starting materials; specimen sintered for 2 hr at 1773 K and cooled in furnace.
4*	19	Durbin, E.A. and Harmon, C.G.	1952	I	298-746	$4MgO \cdot Nb_2O_5$	Magnesium niobium oxide; 99.5 pure MgO and 99.9 pure Nb_2O_5 starting materials; specimen sintered for 2 hr at 1773 K and cooled in furnace.

DATA TABLE 129. THERMAL LINEAR EXPANSION OF MAGNESIUM NIOBIUM OXIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
298	0.003
373	0.049
473	0.107
508	0.120
531	0.123
573	0.132
629	0.159
673	0.196
718	0.240
CURVE 2*	
298	0.003
373	0.043
473	0.086
573	0.130
673	0.182
773	0.244
873	0.312
973	0.376
1048	0.413
CURVE 3*	
298	0.002
373	0.032
473	0.077
525	0.086
573	0.098
630	0.126
673	0.162
695	0.183
773	0.231
873	0.296
928	0.335
CURVE 4*	
298	0.003
373	0.054
442	0.106
473	0.128
523	0.153
573	0.180
628	0.219
673	0.265
746	0.356

* No figure given.

SPECIFICATION TABLE 130. THERMAL LINEAR EXPANSION OF POTASSIUM NIOBIUM OXIDE $K_2O \cdot Nb_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	293	Weirauch, D. F. and Tennery, V. J.	1967	L	298-773		Raw materials reagent grade K_2CO_3, purified Ag_2O, and optical grade I (> 99.9) Nb_2O_5, mixed dry, and mixed in methyl alcohol and pestle, dried, drymixed and calcined at 1073 K for 4 hr; pellet pressed from calcined powder; pure $KNbO_3$ specimen fired at 1313 K for 15 min; sintered pellet crushed to -200 mesh, pressed into pellet 0.625 in. diameter and 0.25 in. thick, refired for 15 min at selected temperature; orthorhombic to tetragonal transition temperature at 478 K and tetragonal to cubic transition temperature at 682 K; zero-point correction of 0.002% determined by graphical extrapolation.
2*	294	Shirane, G., Newnham, R., and Pepinsky, R.	1954	X	298-783		Specimen prepared from mixture of K_2CO_3 and Nb_2O_5; firing temperature 1323 K; expansion measured along a-axis; lattice parameter reported at 298.2 K is 4.0375 Å of orthorhombic structure; 4.0375 Å at 293.2 K determined by graphical extrapolation.
3*	294	Shirane, G., et al.	1954	X	298-783		The above specimen; expansion measured along b-axis; lattice parameter reported at 298.2 K is 3.9711 Å of orthorhombic structure; 3.9707 Å at 293.2 K determined by graphical extrapolation.
4*	294	Shirane, G., et al.	1954	X	298-683		The above specimen; expansion measured along c-axis; lattice parameter reported at 298.2 K is 4.0375 Å of orthorhombic structure; 4.0375 Å at 293.2 K determined by graphical extrapolation.

DATA TABLE 130. THERMAL LINEAR EXPANSION OF POTASSIUM NIOBIUM OXIDE $K_2O \cdot Nb_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
298	0.002
348	0.021
373	0.029
398	0.039
423	0.048
449	0.059
473	0.068
484	0.068
502	0.070
523	0.082
548	0.096
574	0.110
599	0.124
623	0.139
648	0.152
664	0.157
679	0.158
683	0.133

CURVE 1 (cont.)*

T	$\Delta L/L_0$
703	0.133
723	0.143
748	0.159
773	0.175

CURVE 2*

T	$\Delta L/L_0$
298	0.0000 orth.
398	-0.0024
458	-0.0397
478	-0.0148

T	a(Å)
493	3.9972 t.
503	33.9978
543	3.9992
593	4.0023

CURVE 2 (cont.)*

T	a(Å)
648	4.0048
683	4.0080
698	4.0214 cub.
723	4.0225
783	4.0252

T	$\Delta L/L_0$

CURVE 3*

T	a(Å)
298	0.0100 orth.
398	0.2266
458	0.0397
478	0.3324

T	b(Å)
493	3.9972 t.

CURVE 3 (cont.)*

T	b(Å)
503	3.9978
543	3.9992
593	4.0023
648	4.0048
683	4.0080
698	4.0214 cub.
723	4.0225
783	4.0252

T	$\Delta L/L_0$

CURVE 4*

T	$\Delta L/L_0$
298	0.0000 orth.
398	-0.0094
458	-0.0297
478	-0.0148

CURVE 4 (cont.)*

T	c(Å)
493	4.0636 t.
503	4.0640
543	4.0647
593	4.0639
648	4.0620
683	4.0567

* No figure given.

SPECIFICATION TABLE 131. THERMAL LINEAR EXPANSION OF SODIUM NIOBIUM OXIDE $Na_2O \cdot Nb_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	294	Shirane, G., Newnham, R., and Pepinsky, R.	1954	X	293-943		Specimen prepared from mixture of 5.3 g Na_2CO_3, 13.3 g Nb_2O_5, 8.9 g NaF; heated to 1773 K in platinum crucible, then cooled to 1173 K for 7 hr; rectangular plate yellow color, well-shaped, thin plate up to 1 x 3 x 3 mm in size produced; impurities 0.005 K, <0.001 Li, <<0.001 Rb; specimen consisting of powdered $NaNbO_3$ crystal sealed in glass capillary; crystal structure is orthorhombic when temperature below 633 K, tetragonal when below 753 K, cubic when above 753 K; expansion measured along a-axis; lattice parameter reported at 293.2 K is 3.915 Å for orthorhombic structure.
2*	294	Shirane, G., et al.	1954	X	293-94?		The above specimen; expansion measured along b-axis; lattice parameter reported at 293.2 K is 3.880 Å for orthorhombic structure.
3*	294	Shirane, G., et al.	1954	X	293-693		The above specimen; expansion measured along c-axis; lattice parameter reported at 293.2 K is 3.915 Å for orthorhombic structure.

DATA TABLE 131. THERMAL LINEAR EXPANSION OF SODIUM NIOBIUM OXIDE $Na_2O \cdot Nb_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*		CURVE 3*	
293	0.000 orth.	293	0.000 orth.	293	0.000
448	0.077	448	0.464	448	0.077
573	0.153	573	0.773	573	0.153
623	0.179	623	0.851	623	0.179
T	a(Å)	T	b(Å)	T	c(Å)
648	3.918 t.	648	3.918 t.	648	3.927 t.
663	3.919	663	3.918	663	3.927
683	3.921	683	3.921	683	3.926
693	3.921	693	3.921	693	3.927
703	3.925	703	3.925		
733	3.926	733	3.926		
753	3.928	753	3.928		
943	3.942 cub.	943	3.942 cub.		

* No figure given.

SPECIFICATION TABLE 132. THERMAL LINEAR EXPANSION OF HAFNIUM TANTALUM OXIDE $6HfO_2 \cdot Ta_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	251	Cline, C.F. and Lewis, G.	1957	L	298, 1623		No details given.

DATA TABLE 132. THERMAL LINEAR EXPANSION OF HAFNIUM TANTALUM OXIDE $6HfO_2 \cdot Ta_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.0000
1623	1.1461

* No figure given.

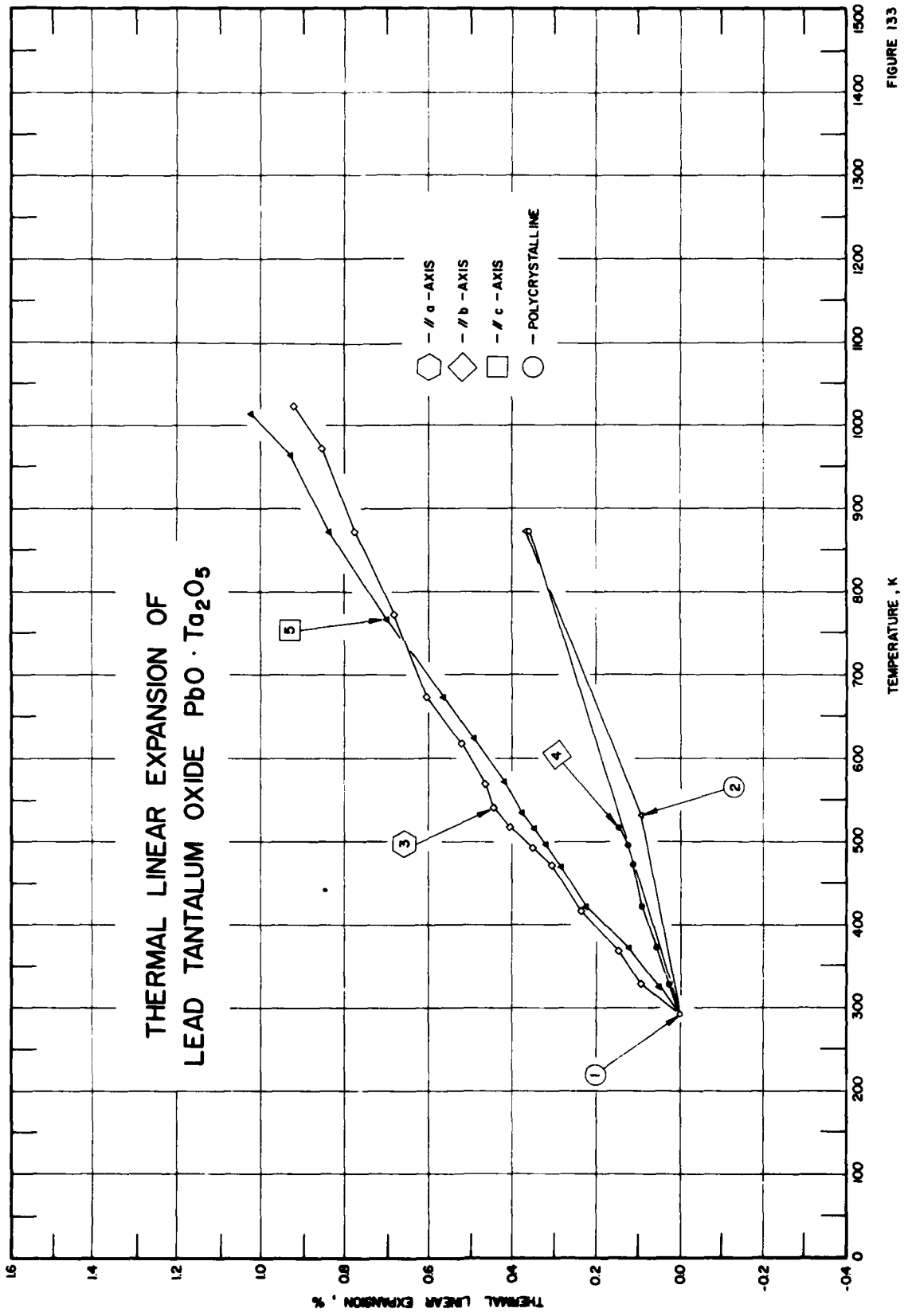

THERMAL LINEAR EXPANSION OF
LEAD TANTALUM OXIDE PbO · Ta2O5
// a -AXIS
// b -AXIS
// c -AXIS
POLYCRYSTALLINE
1
2
3
4
5
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 133

SPECIFICATION TABLE 133. THERMAL LINEAR EXPANSION OF LEAD TANTALUM OXIDE $PbO \cdot Ta_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	805	Subbarao, E.C.	1961	L	293, 873		Rhombohedral, reagent-grade PbO (impurity 0.14 alkalis and alkaline earths) and Ta_2O_5 (99.5% grade) from Kennametal Incorporated weighed to nearest 0.1 g, mixed in glass mortar with acetone until dry; heated in covered platinum crucibles at 473 K to 673 K for several hr; sintering temperature 1223 K.
2	805	Subbarao, E.C.	1961	L	293-873		Orthorhombic, similar to the above specimen; sintering temperature 1723 K; phase change at 533 K.
3	859	Ismailzade, I.G.	1966	X	293-1024	$PbTa_2O_6$	Polycrystalline sample in form of ceramic disk, 10 mm in diameter; synthesized by Academy of Science (USSR); sintered at 1480 C for 1 hr; lattice parameter measured along a-axis; 17.633 Å reported at 293 K.
4	859	Ismailzade, I.G.	1966	X	293-519	$PbTa_2O_6$	The above specimen; lattice parameter measured along b-axis; 17.695 Å reported at 293 K.
5	859	Ismailzade, I.G.	1966	X	293-1014	$PbTa_2O_6$	The above specimen; lattice parameter measured along c-axis; 7.758 Å reported at 293 K.

DATA TABLE 133. THERMAL LINEAR EXPANSION OF LEAD TANTALUM OXIDE $PbO \cdot Ta_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
873	0.360
CURVE 2	
293	0.000
533	0.096
873	0.368
CURVE 3	
293	0.000
329	0.096
369	0.147
418	0.238
472	0.306
493	0.352
CURVE 3 (cont.)	
519	0.403
542	0.442
570	0.465
619	0.522
673	0.607
773	0.681
873	0.777
973	0.856
1024	0.924
CURVE 4	
293	0.000
329	0.028
373	0.057
423	0.090
473	0.113
CURVE 4 (cont.)	
497	0.124
519	0.147
CURVE 5	
293	0.000
326	0.053
373	0.122
423	0.223
470	0.285
497	0.321
517	0.348
535	0.379
573	0.420
625	0.495
672	0.563
768	0.701
CURVE 5 (cont.)	
873	0.839
965	0.931
1014	1.022

SPECIFICATION TABLE 134. THERMAL LINEAR EXPANSION OF LEAD TANTALUM OXIDE $2PbO \cdot Ta_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	805	Subbaras, E.C.	1961	L	293, 873		Pyrochlore-type structure, rhombohedral cell parameters a_R = 10.691 a.u., α_R = 88°19'; required amounts of reagent-grade PbO (impurity 0.14 alkalis and alkaline earths) and Ta_2O_5 (99.5% grade) from Kennametal, Incorporated weighed to nearest 0.1 mg, mixed in glass mortar with acetone until dry; heated in covered platinum crucibles at 473 K to 673 K for several hr; sintering temperature 1573 K.

DATA TABLE 134. THERMAL LINEAR EXPANSION OF LEAD TANTALUM OXIDE $2PbO \cdot Ta_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
873	0.545

* No figure given.

SPECIFICATION TABLE 135. THERMAL LINEAR EXPANSION OF LEAD TANTALUM OXIDE $3PbO \cdot 2Ta_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	805	Subbarao, E.C.	1961	L	293, 873		Cubic pyrochlore type structure with a = 10.551 a.u.; required amounts of reagent-grade PbO (alkalis and alkaline earths ~0.14% as the only impurity in excess of 0.1%) and Ta_2O_5 (99.5% grade) weighed to the nearest 0.1 mg and mixed in glass mortar with acetone until dry; heated in covered platinum crucibles at 473 K to 673 K for several hr; sintering temperature 1573 K.

DATA TABLE 135. THERMAL LINEAR EXPANSION OF LEAD TANTALUM OXIDE $3PbO \cdot 2Ta_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

293	0.000
873	0.377

* No figure given.

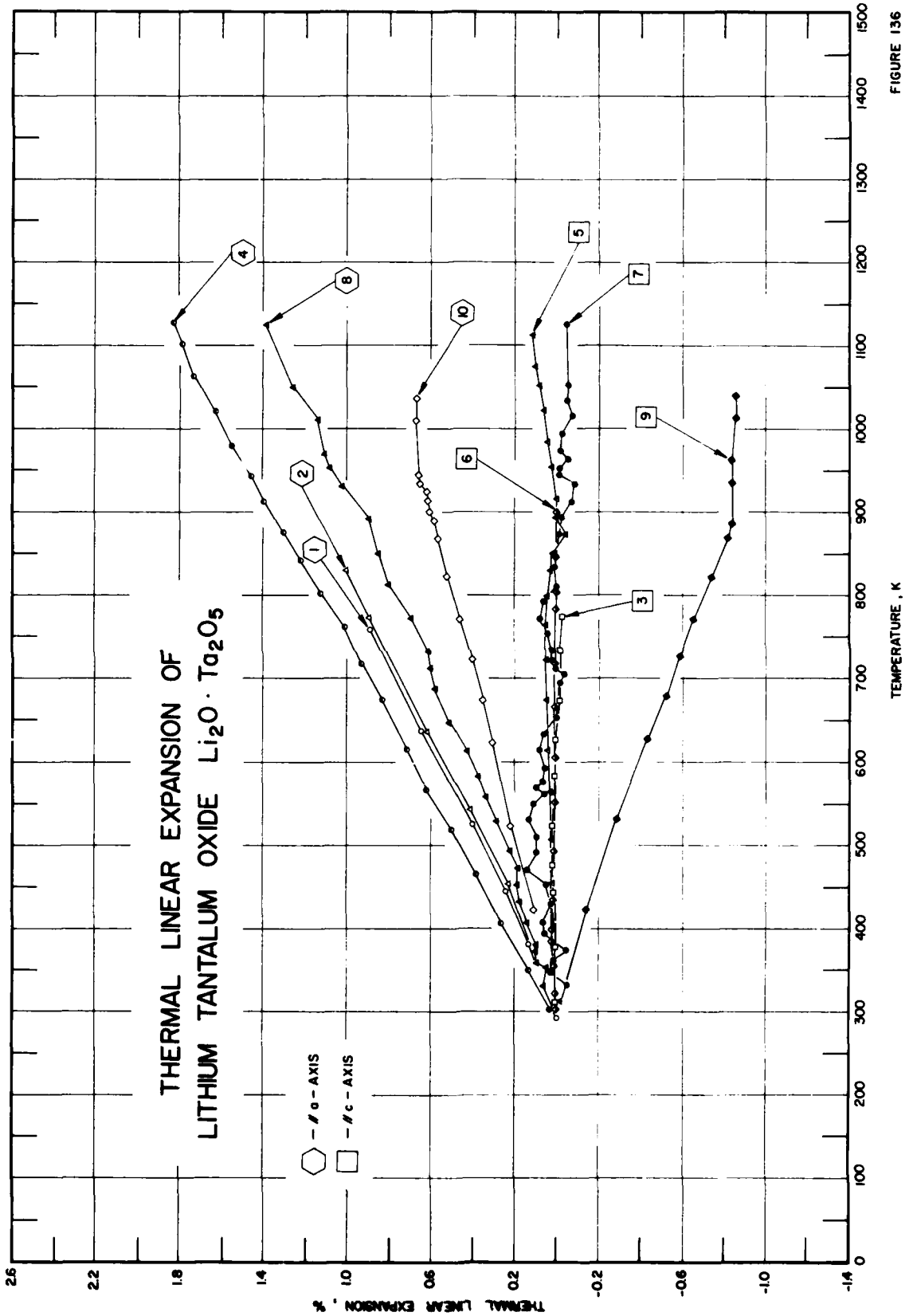

THERMAL LINEAR EXPANSION OF
LITHIUM TANTALUM OXIDE $Li_2O \cdot Ta_2O_5$
⬡ – // a – AXIS
□ – // c – AXIS
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
2.6
2.2
1.8
1.4
1.0
0.6
0.2
-0.2
-0.6
-1.0
-1.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1
2
3
4
5
6
7
8
9
10

FIGURE 136

SPECIFICATION TABLE 136. THERMAL LINEAR EXPANSION OF LITHIUM TANTALUM OXIDE $Li_2O \cdot Ta_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	195	Kim, Y.S. and Smith, R.T.	1969	X	293-759		Single crystal, ferroelectric, grown by the Czochralski technique; thin, parallel-side specimen plates of approximate dimensions 0.6 cm x 0.25 cm x 0.05 cm, prepared from the electrically poled crystal boules; iron (Kα) radiation used (λ = 1.9373 Å); material supplied by Isomet Corporation, Palisades Park, N.J.; at 298 K; d = 1.289 Å on plane (22.0); plate normal aligned with the crystallographic x-axis.
2	195	Kim, Y.S. and Smith, R.T.	1969	X	293-830		Similar to the above specimen; d = 1.488 Å at 298 K on plane (03.0); plate normal aligned with the crystallographic y-axis; Curie temperature 874 K.
3	195	Kim, Y.S. and Smith, R.T.	1969	X	293-774		Similar to the above specimen; d = 1.148 Å at 298 K on plane (00.12); plate normal aligned with the crystallographic z-axis; Curie temperature 874 K.
4	806	Iwasaki, H., Toyoda, H., and Kubota, H.	1967	L	293-1129		Crystal grown with pale green color by pulling from the melt; Curie point at 903 K; lattice constant measured along a-axis; data from smoothed curve; lattice constant reported at 293 K is 5.143 Å.
5	806	Iwasaki, H., et al.	1967	L	293-1113		Similar to the above specimen; lattice constant measured along c_H-axis; lattice constant reported at 293 K is 13.756 Å.
6	807	Roitberg, M.B., Rabinovich, A.Z., Rigerman, L.G., Shapiro, Z.I., Tomashpol'skii, Yu.Ya., and Venevtsev, Yu.N.	1969	L	303-916		Specimen 10 mm^2 x 30 mm long; c-cut single crystal; expansion measured along c-axis; temperature increase rate 200 C per hr; reported error ±1.6%.
7	807	Roitberg, M.B., et al.	1969	X	293-1126		Polycrystalline specimen; expansion along c-axis.
8	807	Roitberg, M.B., et al.	1969	X	293-1125		The above specimen; expansion along a-axis.
9	720	Shapiro, Z.I., Fedulov, S.A., Venevtsev, Yu.N., and Rigerman, L.G.	1965	X	293-1041		Sinters of specimen made from mixtures of analytical grade lithium carbonate and pentoxides; by double firing at 1100 and 1350 C; crystals grown by Czochralski's method to diameter of 5-8 mm and lengths of 40-50 mm; expansion measured for hexagonal cell along c-axis.
10	720	Shapiro, Z.I., et al.	1965	X	293-1037		The above specimen; expansion measured for hexagonal cell along a-axis.

DATA TABLE 136. THERMAL LINEAR EXPANSION OF LITHIUM TANTALUM OXIDE $Li_2O \cdot Ta_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
296	0.006*
381	0.138
445	0.241
527	0.404
637	0.645
759	0.889
CURVE 2	
293	0.000*
297	0.010*
380	0.141*
454	0.235
544	0.422
636	0.628
773	0.897
830	1.002
CURVE 3	
293	0.000*
299	0.006*
313	0.007
379	0.009
444	0.018
478	0.027
524	0.025
583	0.015
628	0.003
673	-0.007
734	-0.017
774	-0.029
CURVE 4	
293	0.000*
302	0.039
350	0.136
408	0.272
465	0.389
520	0.506
568	0.622
615	0.719
675	0.836
718	0.933
762	1.050
803	1.128
841	1.225
876	1.303
914	1.400
942	1.458
980	1.556
1021	1.633
1064	1.730
1102	1.789
1129	1.847
CURVE 5	
293	0.000*
403	0.014
455	0.022
508	0.029
563	0.036
614	0.044
673	0.051
721	0.053
764	0.051
800	0.048
830	0.036
851	0.029
873	-0.044
892	0.007
916	0.007
953	0.029
983	0.044
1021	0.065
1051	0.080
1075	0.094
1113	0.116
CURVE 6‡	
303	0.003
322	0.008
356	0.017
384	0.022
400	0.023
434	0.020
493	0.014
552	0.012
606	0.014
666	0.015
719	0.014
783	0.008
805	0.005
847	0.002
900	0.008
916	0.013*
CURVE 7	
293	0.000*
311	0.050*
332	-0.052
348	0.035
362	0.017
373	-0.041
381	0.021*
393	0.065
409	0.069
430	0.035
452	0.099
471	0.142
490	0.099
510	0.099
531	0.131
551	0.118
561	0.062
570	0.102
577	0.069
592	0.062
614	0.082
632	0.068
652	0.005
674	-0.024*
694	-0.003
704	-0.035
711	0.017
721	0.033
734	0.033
752	0.046
771	0.080
792	0.067
811	0.001
833	0.017
852	0.037*
873	-0.001
894	-0.028
911	-0.078
934	-0.088
945	-0.001
952	-0.012
963	0.030
974	-0.018
993	-0.028
1016	-0.075
1035	-0.044
1053	-0.053
1126	-0.044
CURVE 8	
293	0.000*
312	-0.016
331	0.068
353	0.050
359	0.089
372	0.095
380	0.095
389	0.095*
409	0.142
432	0.175
452	0.188
472	0.188
493	0.225
513	0.270*
530	0.293
548	0.322*
559	0.340
571	0.355*
582	0.378
591	0.396*
613	0.431
629	0.470*
649	0.516
670	0.543*
687	0.584
701	0.608*
712	0.608
720	0.608*
732	0.617
749	0.664*
772	0.695
795	0.730*
812	0.805
829	0.823*
850	0.854
874	0.854*
891	0.897
912	0.959*
930	1.025
940	1.054*
952	1.083
962	1.066*
970	1.108
995	1.137*
1011	1.144
1031	1.244*
1050	1.262
1125	1.386
CURVE 9	
293	0.000*
424	-0.145
532	-0.283
628	-0.418
678	-0.523
727	-0.588
771	-0.653
824	-0.740
870	-0.813
887	-0.835
901	-0.835*
915	-0.835*
925	-0.835*
937	-0.835
951	-0.835*
964	-0.835
1014	-0.856
1041	-0.856
CURVE 10	
293	0.000*
422	0.116
524	0.221
622	0.303
673	0.359
723	0.409
771	0.467
823	0.524
869	0.566
890	0.586
901	0.603
914	0.613
925	0.621
933	0.656
945	0.662
962	0.662
1010	0.675
1037	0.675

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 136. COEFFICIENT OF THERMAL LINEAR EXPANSION OF LITHIUM TANTALUM OXIDE $Li_2O \cdot Ta_2O_5$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 6*, ‡	
303	2.66
322	2.93
356	2.32
384	1.10
400	0.09
434	-1.41
493	-0.72
552	0.09
606	0.39
666	0.09
719	-0.64
783	-1.26
805	-1.26
847	0.14
900	2.16
916	3.16

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 137. THERMAL LINEAR EXPANSION OF NIOBIUM TANTALUM OXIDE $2Nb_2O_5 \cdot Ta_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	333	Brown, J.J., Jr.	1964	X	313-1273		Nb_2O_5 and Ta_2O_5 mixed by molar ratio 2:1; annealed platinum powder used as internal standard; expansion measured along a-axis; data from smoothed curve; zero-point correction 0.012%.
2*	333	Brown, J.J., Jr.	1964	X	313-1273		The above specimen; expansion measured along c-axis; data from smoothed curve.
3*	333	Brown, J.J., Jr.	1964	L	313-1273		Aggregated bar specimen, approximately 10 x 1 x 1 cm; heated at 125 C per hr in Nichrome-Wound vertical tube furnace; data from smoothed curve.

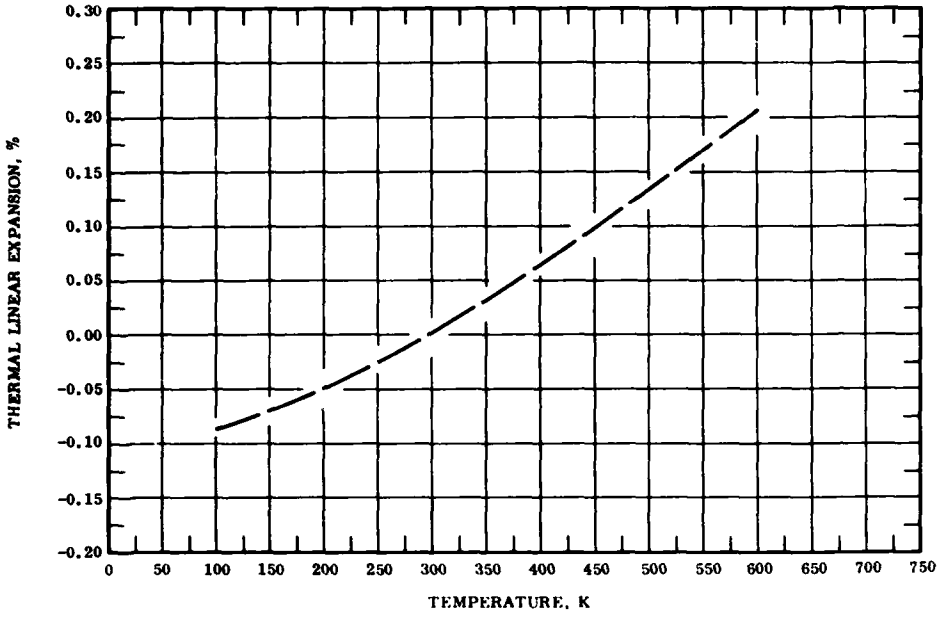
DATA TABLE 137. THERMAL LINEAR EXPANSION OF NIOBIUM TANTALUM OXIDE $2Nb_2O_5 \cdot Ta_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*		CURVE 3*	
313	0.012	313	0.000	313	0.000
373	0.047	373	0.000	373	-0.005
473	0.098	473	0.000	473	-0.009
573	0.152	573	0.000	573	-0.012
673	0.205	673	0.003	673	-0.012
773	0.256	773	0.007	773	-0.010
873	0.313	873	0.011	873	-0.006
973	0.367	973	0.016	973	-0.003
1073	0.421	1073	0.022	1073	0.002
1173	0.479	1173	0.029	1173	0.008
1273	0.528	1273	0.037	1273	0.015

* No figure given.

FIGURE AND TABLE NO. 138R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF POTASSIUM TANTALUM OXIDE $K_2O \cdot Ta_2O_5$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
100	-0.086	2.9
150	-0.069	3.8
200	-0.048	4.6
250	-0.024	5.3
293	0.000	5.8
350	0.035	6.3
400	0.067	6.7
450	0.101	7.0
500	0.137	7.1
550	0.172	7.2
600	0.208	7.2

REMARKS

The provisional values are based on the most recent x-ray measurements and are considered accurate to within ± 7%. No weight is given to curve 2 in the analysis. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.105 + 8.013 \times 10^{-5} T + 1.151 \times 10^{-6} T^2 - 6.899 \times 10^{-10} T^3$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ± 7%.

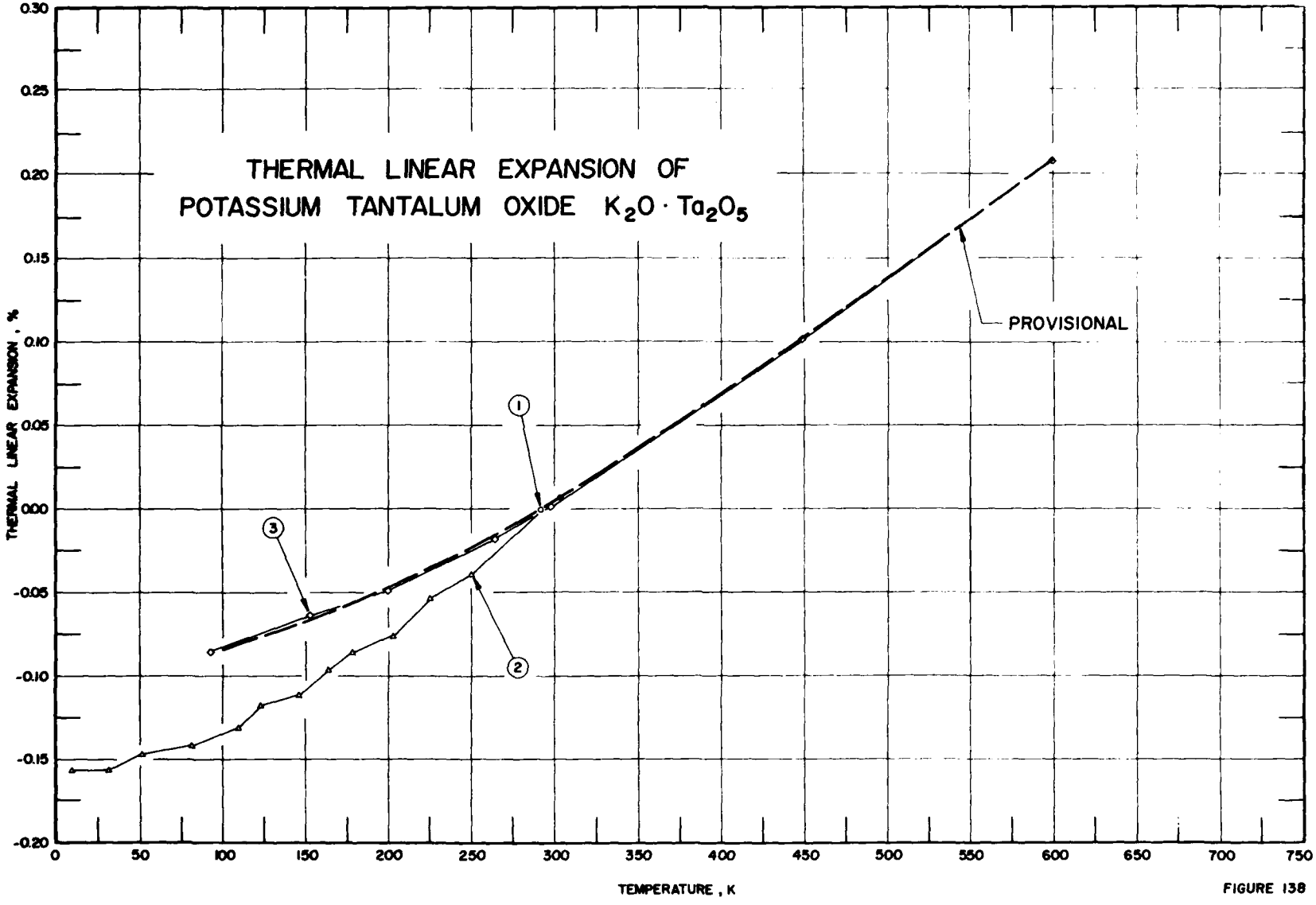

THERMAL LINEAR EXPANSION OF
POTASSIUM TANTALUM OXIDE $K_2O \cdot Ta_2O_5$
PROVISIONAL
1
2
3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.30
0.25
0.20
0.15
0.10
0.05
.000
-.05
-.10
-.15
-.20
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750

FIGURE 138

SPECIFICATION TABLE 138. THERMAL LINEAR EXPANSION OF POTASSIUM TANTALUM OXIDE $K_2O \cdot Ta_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	821	Smakula, A.	1967		293-303	$KTaO_3$ potassium tantalate	Single crystal, of a few cubic centimeters with well formed cubic faces; colorless crystal by decreasing the K_2CO_3 from 65 mole percent to 55 mole percent; melting temperature 1340 C; thermal expansion coefficient determined by hydrostatic weighing using 1.3-dibromopropane as the immersing liquid.
2	820	Demurov, D.G. and Venevtsev, Venevtsev, Yu.N.	1971	X	10-293	$KTaO_3$ potassium tantalate	Single crystals of potassium metatantalate grown by spontaneous crystallization from solution in melt; charge heated to temperature of 1250 C (3 hr) the cooled (10 degrees/hr) to 600 C; crystals (analytical grade) measured 3 x 2 x 1 mm; expansion measured for well-formed perovskite-type cubic structure; unit cell parameter 3.987 Å reported at 298 K.
3	819	Samara, G.A. and Morosin, B.	1973	X	93-600	$KTaO_3$ potassium tantalate	Three different experimental methods used, above 298 K high-temperature x-ray furnace used for sample of single-crystal ground in form of small sphere; the values at 265 and 200 K obtained using same arrangement but without furnace cover and by blowing cold nitrogen gas directly on crystal specimen; the values at 153 and 93 K obtained by measuring high -2θ on Debye-Scherrer film taken with 15 cm diameter camera; lattice parameter at 1 bar at 298 K is 3.9884 Å.

DATA TABLE 138. THERMAL LINEAR EXPANSION OF POTASSIUM TANTALUM OXIDE $K_2O \cdot Ta_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2 (cont.)	
293	0.000	225	-0.054
303	0.007	250	-0.038
		293	0.000*
CURVE 2		CURVE 3	
10	-0.157		
32	-0.157	93	-0.085
52	-0.147	153	-0.063
82	-0.142	200	-0.048
111	-0.131	265	-0.017
124	-0.117	298	0.002
147	-0.111	450	0.103
164	-0.096	600	0.208
179	-0.085		
203	-0.076		

* Not shown in figure.

SPECIFICATION TABLE 139. THERMAL LINEAR EXPANSION OF BARIUM TIN OXIDE $BaO \cdot SnO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	876	Kirchner, H.P., Gruver, R.M., Platts, D.R., and Walker, R.E.	1967	L	293-1265		Commercial grade specimen, obtained from Titanium Alloy Division of National Lead Company.

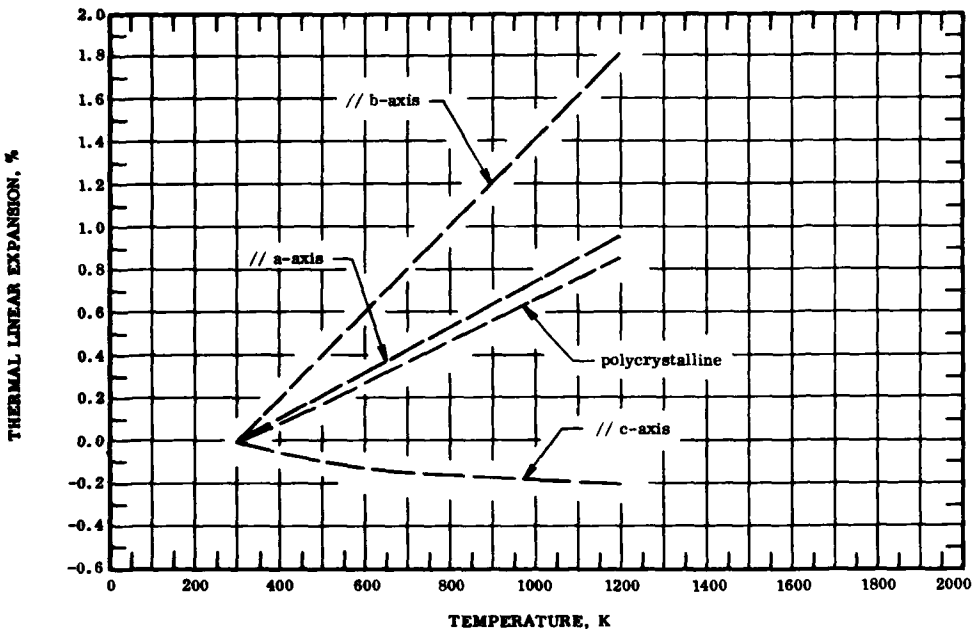
DATA TABLE 139. THERMAL LINEAR EXPANSION OF BARIUM TIN OXIDE $BaO \cdot SnO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
474	0.151
673	0.345
872	0.542
1069	0.758
1265	0.993

* No figure given.

FIGURE AND TABLE NO. 140R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ALUMINUM TITANIUM OXIDE $Al_2O_3 \cdot TiO_2$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// b-axis	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	0.000	8.1
350	0.118	0.059	-0.032	0.048	8.4
400	0.217	0.112	-0.058	0.090	8.6
450	0.319	0.165	-0.081	0.133	8.8
500	0.419	0.217	-0.100	0.179	9.0
550	0.520	0.270	-0.117	0.223	9.2
600	0.620	0.322	-0.132	0.269	9.3
650	0.721	0.375	-0.142	0.320	9.5
700	0.821	0.427	-0.152	0.365	9.6
750	0.921	0.483	-0.160	0.413	9.7
800	1.020	0.531	-0.165	0.462	9.7
850	1.119	0.583	-0.171	0.510	9.8
900	1.218	0.636	-0.176	0.560	9.8
950	1.317	0.608	-0.180	0.610	9.8
1000	1.415	0.740	-0.185	0.656	9.7
1050	1.512	0.792	-0.190	0.705	9.7
1100	1.609	0.845	-0.195	0.753	9.6
1150	1.706	0.897	-0.200	0.801	9.5
1200	1.802	0.950	-0.206	0.848	9.3

REMARKS

The provisional values for the axial thermal expansion are based on the x-ray data for stable material. The values for the polycrystalline material are derived from the selected axial values. This result is recommended in preference to the reported experimental data for polycrystalline samples on the suspicion that those samples exhibit preferential orientation or instability closely related to the intergranular rupture along dissimilar crystallographic planes. The values are considered accurate to within ± 10% and are represented approximately by the following equations:

// b-axis: $\Delta L/L_0 = -0.590 + 2.012 \times 10^{-3}\, T + 3.273 \times 10^{-8}\, T^2 - 4.020 \times 10^{-11}\, T^3$

// a-axis: $\Delta L/L_0 = -0.315 + 1.081 \times 10^{-3}\, T - 4.139 \times 10^{-8}\, T^2 + 1.534 \times 10^{-11}\, T^3$

// c-axis: $\Delta L/L_0 = 0.277 - 1.254 \times 10^{-3}\, T + 1.209 \times 10^{-6}\, T^2 - 4.164 \times 10^{-10}\, T^3$

polycrystalline: $\Delta L/L_0 = -0.207 + 6.030 \times 10^{-4}\, T + 4.153 \times 10^{-7}\, T^2 - 1.540 \times 10^{-10}\, T^3$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equations and are considered accurate to about ± 10%.

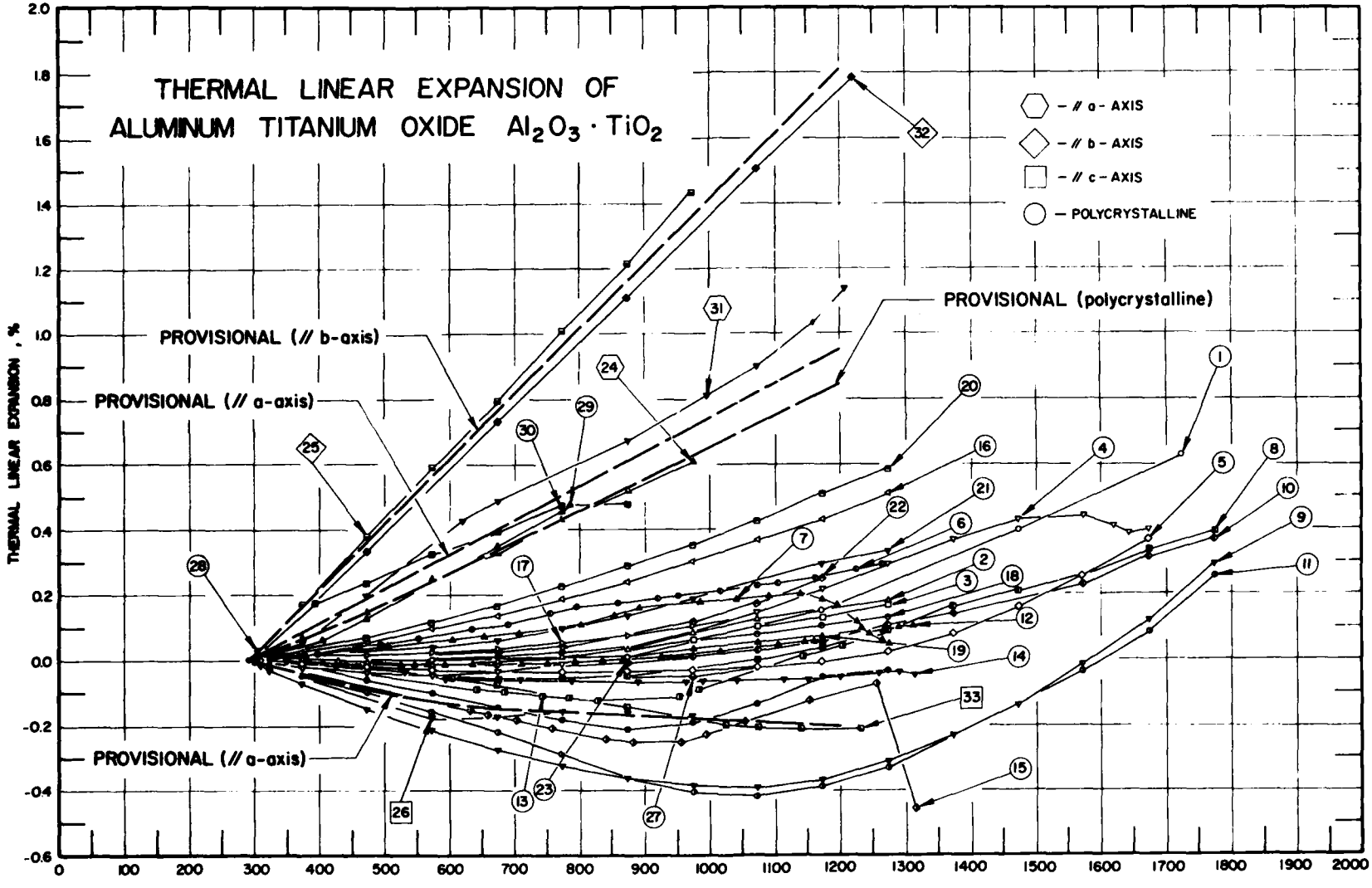

THERMAL LINEAR EXPANSION OF
ALUMINUM TITANIUM OXIDE $Al_2O_3 \cdot TiO_2$
// a - AXIS
// b - AXIS
// c - AXIS
POLYCRYSTALLINE
PROVISIONAL (polycrystalline)
PROVISIONAL (// b-axis)
PROVISIONAL (// a-axis)
PROVISIONAL (// a-axis)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 140

SPECIFICATION TABLE 140. THERMAL LINEAR EXPANSION OF ALUMINUM TITANIUM OXIDE $Al_2O_3 \cdot TiO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	293-1723		Specimen with cross section 1/2 x 1/2 in. and 7 in. long, fine grain, the ends sawed at a rake and to a point.
2	307	McKinstry, H.A.	1949		293-1273		C.P. grade specimen; bulk material calcined 2 hr at 1973 K; fabricated into bar and fired 25 hr at 1773 K.
3	307	McKinstry, H.A.	1949		293-1273		The above specimen; refired 24 hr at 1133 K.
4	307	McKinstry, H.A.	1949		293-1673		Bulk specimen calcined 2 hr at 1973 K, fabricated to bar and fired 25 hr at 1773 K.
5	307	McKinstry, H.A.	1949		293-1673		Specimen fabricated from equimolar raw mix of Al_2O_3 and TiO_2; fired 26 hr at 1773 K.
6	829	Battacharyya, B.N. and Sen, S.	1965		323-1267	T_1 Al_2TiO_5	56.1 Al_2O_3 and 43.9 TiO_2 fired 4 hr at 1923 K in oxidizing atmosphere under 10000 psi pressure to yield Al_2TiO_5; product verified by x-ray analysis.
7	829	Battacharyya, B.N. and Sen, S.	1965		378-1275	T_3 Al_2TiO_5	58.1 Al_2O_3 and 41.9 TiO_2 fired 4 hr at 1723 K under 8,000 psi to yield Al_2TiO_5, verified by x-ray analysis.
8	275	Lang, S.M., Fillmore, C.L., and Maxwell, L.H.	1952		293-1773	β-$Al_2O_3 \cdot TiO_2$	Test specimen was prepared from equimolar proportions of the oxides, Al_2O_3, TiO_2, pressed at 9,400 lb/in^2, and heated at 1,800 C for 1 hr before testing; heating run.
9	275	Lang, S.M., et al.	1952		1773-310	β-$Al_2O_3 \cdot TiO_2$	The above specimen; expansion measured with decreasing temperature; zero-point correction -0.101% determined by graphical extrapolation.
10	275	Lang, S.M., et al.	1952		310-1773	β-$Al_2O_3 \cdot TiO_2$	Similar to the above specimen; expansion measured with increasing temperature.
11	275	Lang, S.M., et al.	1952		1773-303	β-$Al_2O_3 \cdot TiO_2$	The above specimen; expansion measured with decreasing temperature; zero-point correction -0.112%.
12	830	Buessem, W.R. and McKinstry, H.A.	1962	L	301-1311		Polycrystalline specimen sintered at 1748 K; expansion measured with increasing temperature; data received in correspondence with authors; reported error 6.0%.
13	830	Buessem, W.R. and McKinstry, H.A.	1962	L	1311-303		The above specimen; expansion measured with decreasing temperature.
14	830	Buessem, W.R. and McKinstry, H.A.	1962	L	301-1317		Similar to the above specimen except sintered at 1873 K; expansion measured with increasing temperature.
15	830	Buessem, W.R. and McKinstry, H.A.	1962	L	1317-297		The above specimen; expansion measured with decreasing temperature.
16	831	Thielke, N.R.	1953		323-1273		Chemically pure specimen, matured 2 hr at 1473 K.
17	831	Thielke, N.R.	1953		323-1273		Chemically pure specimen, matured 2 hr at 1773 K.
18	831	Thielke, N.R.	1953		323-1273		Chemically pure specimen, matured 2 hr at 1873 K.
19	831	Thielke, N.R.	1953		323-1273		Chemically pure specimen, matured 2 hr at 1973 K.
20	831	Thielke, N.R.	1953		308-1273		Technical grade specimen, matured 2 hr at 1473 K.
21	831	Thielke, N.R.	1953		308-1273		Technical grade specimen, matured 2 hr at 1673 K.
22	831	Thielke, N.R.	1953		308-1273		Technical grade specimen, matured 2 hr at 1873 K.
23	831	Thielke, N.R.	1953		308-1273		Technical grade specimen, matured 2 hr at 1973 K.

SPECIFICATION TABLE 140. THERMAL LINEAR EXPANSION OF ALUMINUM TITANIUM OXIDE $Al_2O_3 \cdot TiO_2$ (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
24	832	Buessem, W.R. and Lange, F.F.	1966	X	298-973		Finely ground specimen; lattice parameter measured along a-axis; 9.4312 Å reported at 298 K; 9.4308 Å at 293 K determined by graphical extrapolation.
25	832	Buessem, W.R. and Lange, F.F.	1966	X	298-973		The above specimen, expansion measured along b-axis; 9.6370 Å reported at 298 K; 9.6359 Å at 293 K determined by graphical extrapolation.
26	832	Buessem, W.R. and Lange, F.F.	1966	X	298-973		The above specimen, expansion measured along c-axis; 3.5902 Å reported at 298 K; 3.5903 Å at 293 K determined by graphical extrapolation.
27	832	Buessem, W.R. and Lange, F.F.	1966	L	298-973		Ceramic specimen, sintered at 1873 K, recycled to 1273 K and cooled; expansion measured with increasing temperature.
28	832	Buessem, W.R. and Lange, F.F.	1966	L	1273-306		The above specimen, expansion measured with decreasing temperature.
29	832	Buessem, W.R. and Lange, F.F.	1966	I	304-787		Cold pressed ceramic specimen formed from powder synthesized at 1873 K; density 3.66 g cm^{-3}; expansion measured with increasing temperature.
30	832	Buessem, W.R. and Lange, F.F.	1966	I	873-393		The above specimen; expansion measured with decreasing temperature.
31	241	Thielke, N.R.	1954	X	300-1209		Expansion measured along a-axis; lattice parameter reported at 300 K is 9.4261 Å.
32	241	Thielke, N.R.	1954	X	296-1220		Expansion measured along b-axis; lattice parameter reported at 296 K is 9.6366 Å.
33	241	Thielke, N.R.	1954	X	302-1230		Expansion measured along c-axis; lattice parameter reported at 302 K is 3.5916 Å

DATA TABLE 140. THERMAL LINEAR EXPANSION OF ALUMINUM TITANIUM OXIDE $Al_2O_3 \cdot TiO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.000
573	0.000
873	0.012
1173	0.149
1473	0.399
1723	0.627
CURVE 2	
293	0.000
373	0.003
430	-0.002
473	-0.004
573	-0.005
673	-0.002
773	0.010
873	0.036
973	0.082
1073	0.123
1173	0.152*
1273	0.177
CURVE 3	
293	0.000*
373	0.004*
430	-0.002*
473	-0.003*
573	-0.004*
673	-0.001*
773	0.008*
873	0.026*
973	0.059
1073	0.099
1173	0.127
1273	0.170
CURVE 4	
293	0.000*
373	-0.020
473	-0.038
573	-0.044
673	-0.036
773	-0.013
873	0.025*
973	0.077*
1073	0.143
1173	0.217
1273	0.292
1373	0.364
1473	0.428
1573	0.440
1621	0.413
1643	0.388
1673	0.400
CURVE 5	
293	0.000*
373	-0.008
473	-0.018
573	-0.027
673	-0.032*
773	-0.035
873	-0.034
973	-0.030
1073	-0.022
1173	-0.006
1273	0.025
1373	0.080
1473	0.160
1573	0.257
1673	0.369
CURVE 6	
323	0.004
353	0.008*
399	0.021
422	0.031*
461	0.042
494	0.050
531	0.067*
553	0.072
580	0.084*
633	0.093
661	0.100*
690	0.109
725	0.125*
757	0.143
796	0.160
828	0.165*
859	0.173
883	0.182*
920	0.188
951	0.197
978	0.205*
1017	0.209
1040	0.213*
1072	0.225
1104	0.234
1137	0.244*
1164	0.249
1188	0.267*
1226	0.274
1267	0.291
CURVE 7	
378	0.017
398	0.021*
454	0.034
506	0.045
604	0.064
653	0.074
707	0.080
802	0.110
854	0.137
891	0.159
985	0.175
1041	0.183
1091	0.193
1140	0.198
1172	0.182
1196	0.167
1226	0.116
1232	0.098
1245	0.080
1264	0.060
1275	0.049
CURVE 8	
293	0.000*
323	0.000*
373	-0.009*
473	-0.032*
573	-0.051*
673	-0.060
773	-0.057
873	-0.046
973	-0.028*
1073	0.000
1173	0.037
1273	0.087
1373	0.162
1473	0.207
1573	0.255*
1673	0.335
1773	0.393
CURVE 9	
1773	0.292
1673	0.120
1573	-0.017
1473	-0.140
1373	-0.235
1273	-0.313
1173	-0.371
1073	-0.396
973	-0.388
873	-0.363
773	-0.326
673	-0.276
573	-0.216
473	-0.150
373	-0.071
323	-0.032
310	-0.018
CURVE 10	
310	0.000
323	0.000*
373	-0.006*
473	-0.011*
573	-0.013*
673	-0.010
773	-0.001
873	0.004*
973	0.011
1073	0.027
1173	0.053
1273	0.101
1373	0.140
1473	0.165*
1573	0.229
1673	0.316
1773	0.368
CURVE 11	
1773	0.256
1673	0.085
1573	-0.038
1473	-0.133*
1373	-0.230*
1273	-0.334
1173	-0.393
1073	-0.421
973	-0.403
873	-0.359*
773	-0.290
673	-0.221
573	-0.161
473	-0.100
373	-0.045
323	-0.018
303	-0.006
CURVE 12	
301	0.000*
339	-0.003*
377	-0.005*
407	-0.008
441	-0.010
527	-0.012
547	-0.012
567	-0.013
593	-0.013
637	-0.013
677	-0.012*
711	-0.012
751	-0.011
793	-0.008
835	-0.004
867	-0.002
927	0.007
977	0.017*
1017	0.027
1105	0.044
1147	0.051
1159	0.055
1243	0.078*
1267	0.086
1289	0.094
1311	0.100
CURVE 13	
1311	0.100*
1309	0.097*
1203	0.041
1143	0.003
1073	-0.034*
983	-0.093
953	-0.116
829	-0.124
783	-0.119
743	-0.112
683	-0.101
643	-0.092
303	0.009*
CURVE 14	
301	0.000*
335	-0.005*
350	-0.008
377	-0.011*
427	-0.019
478	-0.029*
531	-0.039
563	-0.048*
595	-0.050
629	-0.055*
673	-0.058*

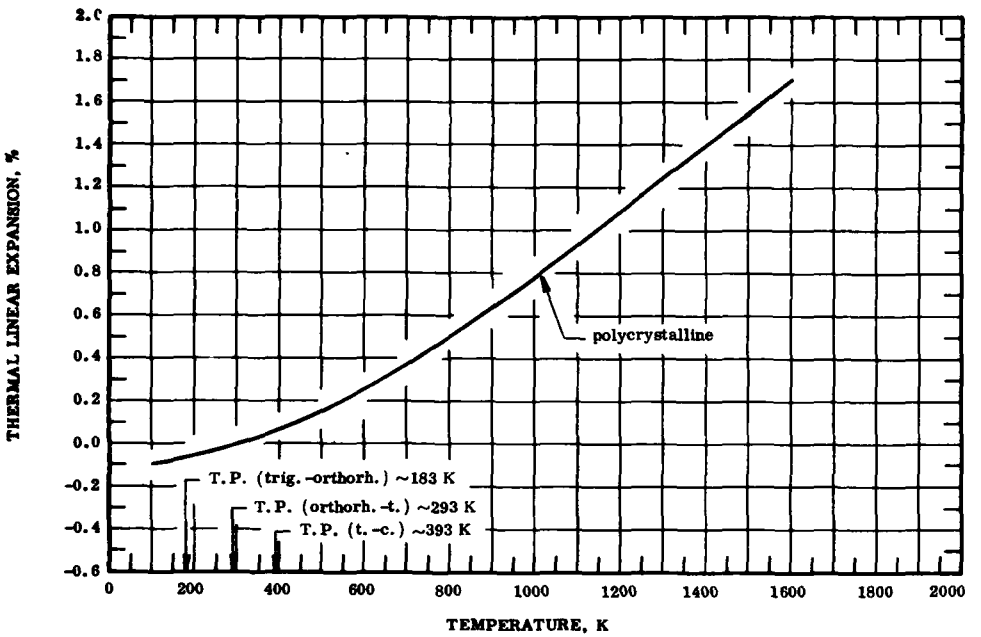
* Not shown in figure.

DATA TABLE 140. THERMAL LINEAR EXPANSION OF ALUMINUM TITANIUM OXIDE $Al_2O_3 \cdot TiO_2$ (continued)

T	$\Delta L/L_0$
CURVE 14 (cont.)	
709	-0.062
749	-0.065*
789	-0.068
819	-0.071*
859	-0.072*
891	-0.073
941	-0.073*
964	-0.073
989	-0.073
1041	-0.069
1087	-0.068*
1113	-0.065
1151	-0.062
1201	-0.053
1260	-0.042
1291	-0.070
1317	-0.046
CURVE 15	
1317	-0.484
1255	-0.102
1155	-0.153
1057	-0.217
993	-0.255
957	-0.280
883	-0.277
841	-0.267
759	-0.235
703	-0.212
659	-0.193
633	-0.183
297	0.000*
CURVE 16	
323	0.009*
373	0.023
473	0.057
573	0.095
673	0.137
773	0.186
873	0.239
973	0.299
1073	0.364
1173	0.430
1273	0.506
CURVE 17	
323	0.002*
373	0.006*
473	0.015
573	0.024
673	0.035
773	0.053
873	0.077
973	0.104
1073	0.130*
1173	0.154*
1273	0.170*
CURVE 18	
323	0.000*
373	0.001*
473	0.005*
573	0.005*
673	0.009
773	0.021
873	0.037*
973	0.057*
1073	0.079
1173	0.104
1273	0.129
CURVE 19	
323	0.001*
373	0.002*
473	0.006*
573	0.006*
673	0.005*
773	0.010*
873	0.021*
973	0.035
1073	0.051
1173	0.070
1273	0.091*
CURVE 20	
308	0.000*
373	0.024*
473	0.064
573	0.110
673	0.162
773	0.221
873	0.286
973	0.350
1073	0.422
1173	0.504
1273	0.580
CURVE 21	
308	0.000*
373	0.008*
473	0.021*
573	0.038
673	0.060
773	0.093
873	0.134
973	0.184
1073	0.235*
1173	0.289
1273	0.328
CURVE 22	
308	0.000*
373	0.003*
473	0.009*
573	0.015*
673	0.025
773	0.043
873	0.070*
973	0.113
1073	0.170
1173	0.246
1273	0.324*
CURVE 23	
308	0.000*
373	0.003*
473	-0.006*
573	-0.013*
673	-0.017*
773	-0.015*
873	-0.007
973	0.010*
1073	0.033*
1173	0.075*
1273	0.131*
CURVE 24	
298	0.004*
373	0.068
473	0.159
573	0.248
673	0.336
773	0.426
873	0.520
973	0.607
CURVE 25	
298	0.011*
373	0.171
473	0.379
573	0.587
673	0.794
773	1.007
873	1.215
973	1.432
CURVE 26	
298	-0.003*
373	-0.039*
473	-0.092*
573	-0.175
673	-0.175
773	-0.161
873	-0.161
973	-0.175
CURVE 27	
293	0.000*
373	-0.004*
473	-0.018*
573	-0.026*
673	-0.037*
773	-0.049*
873	-0.049*
973	-0.049
1073	-0.031*
1173	0.000*
1273	0.034*
CURVE 28	
1273	0.034
1173	-0.057
1073	-0.136
973	-0.193
873	-0.212
773	-0.183
673	-0.145
573	-0.102
473	-0.059
373	0.000*
306	0.029
CURVE 29	
304	0.005
373	0.037*
403	0.061
473	0.130
573	0.241*
673	0.347
773	0.456
787	0.477
CURVE 30	
873	0.477
773	0.470
673	0.393
573	0.313
473	0.235
393	0.173
CURVE 31	
300	0.005*
373	0.057
473	0.197
620	0.423
673	0.484
874	0.669
998	0.807
1073	0.896
1161	1.033
1209	1.135
CURVE 32	
296	0.005*
473	0.334
673	0.729
873	1.110
1073	1.502
1220	1.784
CURVE 33	
302	-0.003*
473	-0.033*
604	-0.056
673	-0.075
873	-0.147
974	-0.189*
1023	-0.200
1073	-0.209
1141	-0.214
1230	-0.214

* Not shown in figure.

FIGURE AND TABLE NO. 141R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF BARIUM TITANIUM OXIDE $BaO \cdot TiO_2$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, $10^{-6}\ K^{-1}$]

T	$\Delta L/L_0$	α
100	-0.100	2.7
150	-0.075	3.7
200	-0.052	4.6
250	-0.025	5.6
293	0.000	6.3
350	0.038	7.3
400	0.077	8.1
500	0.165	9.6
600	0.268	10.9
700	0.383	12.1
800	0.510	13.1
900	0.645	14.0
1000	0.789	14.7
1100	0.940	15.2
1200	1.093	15.6
1300	1.251	15.9
1400	1.410	16.0
1500	1.569	16.0
1600	1.727	16.0

REMARKS

The recommended values are based on the data for heat-treated polycrystalline samples (curves 1, 3, 4, 11, and 17 to 20). No weight is given to curves 5 to 8 which are about 10% higher than the recommended values because those samples are not heat-treated and subject to the cracking above 1100 K. These values are considered accurate to within ± 5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.104 + 5.395 \times 10^{-5}\ T + 1.102 \times 10^{-6}\ T^2 - 2.628 \times 10^{-10}\ T^3$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ± 10%.

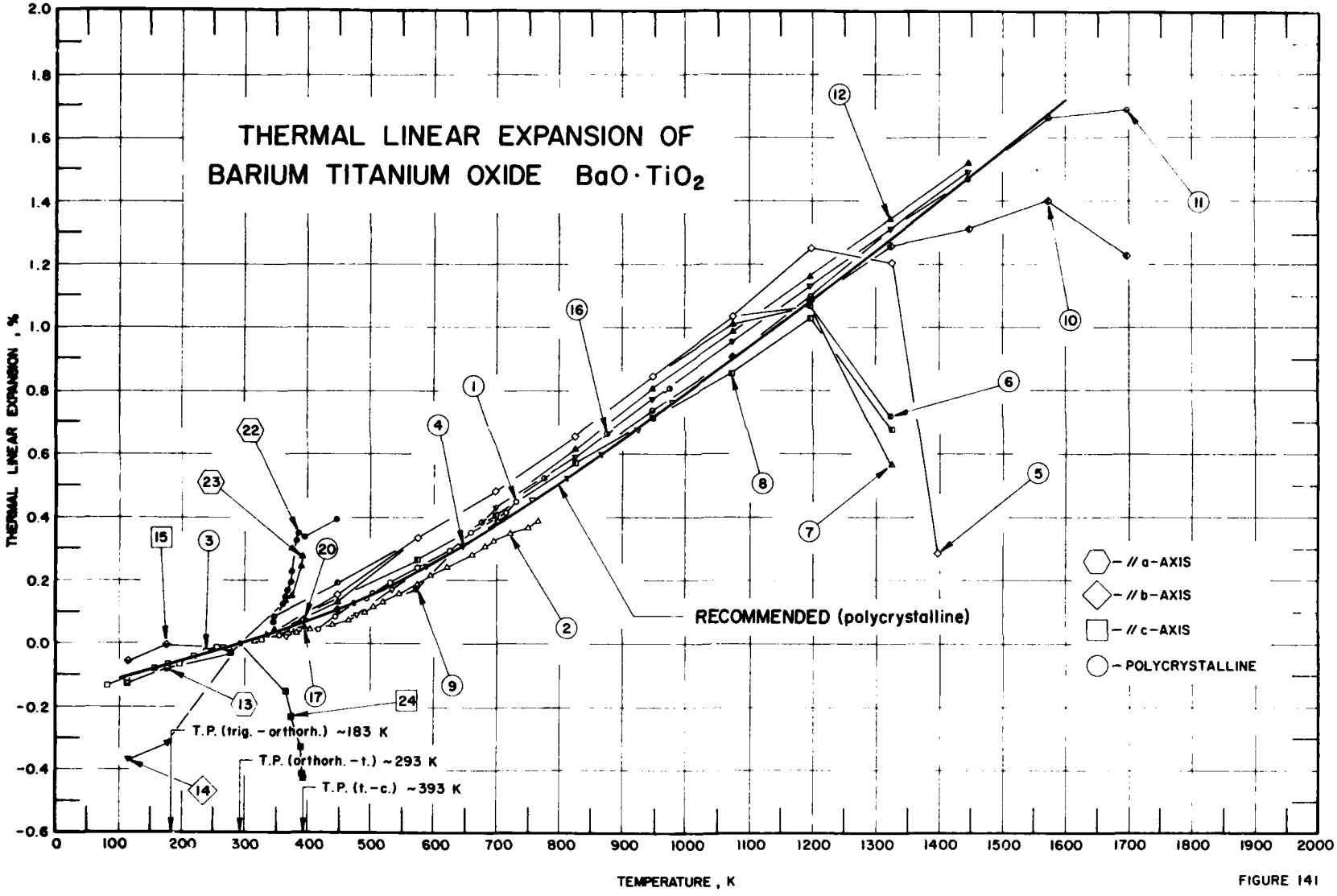

THERMAL LINEAR EXPANSION OF
BARIUM TITANIUM OXIDE BaO·TiO2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED (polycrystalline)
// a-AXIS
// b-AXIS
// c-AXIS
POLYCRYSTALLINE
T.P. (trig. - orthorh.) ~183 K
T.P. (orthorh. - t.) ~293 K
T.P. (t. - c.) ~393 K

FIGURE 141

SPECIFICATION TABLE 141. THERMAL LINEAR EXPANSION OF BARIUM TITANIUM OXIDE $BaO \cdot TiO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	833	Ulrich, D.R. and Smoke, E.J.	1966	I	293-730		Pure barium titanate glass made by the melting and rapid quenching of small particles of C.P. grade barium titanate, obtained from Titanium Alloy Manufacturing Division, National Lead Company, Niagara Falls, N.Y., using flame-spray process; powdered material melted in oxygen acetylene flame and quenched in distilled water; specimen pressed from flame; sprayed particles and fired in electrically wound tube furnace; solid sintered.
2	833	Ulrich, D.R. and Smoke, E.J.	1966	I	293-765		Similar to the above specimen except devitrified.
3	834	Keyston, J.R.G., Macpherson, J.D., and Guptill, E.W.	1957		81-375	$BaTiO_3$	Expansion measurement based on the measurement of resonant frequency of one or more modes of microwave cavity made of Barium Titanium oxide; zero-point correction -0.132%.
4	181	Smoke, E.Y., Rooda, J., Sirkis, M.D., Holsberg, P.J., Malony, D.A., and Choa, C.	1960	L	366-978		Pure specimen; fired at 1728 K, 0.00 % water absorption, bulk density 5.28 g cm^3.
5	835	Skinner, K.G.	1962	L	348-1398	TAM	Dry pressed at 10,000 psi using 2.5% paraffin and 0.04% Co.; unfired; supplied by the Titanium Alloy Manufacturing Division, National Lead Co.
6	835	Skinner, K.G.	1962	L	348-1323	TAM	Similar to the above specimen; calciner discharge, 20 mesh.
7	835	Skinner, K.G.	1962	L	348-1323	Drakenfeld	Dry pressed at 10,000 psi using 2.5% paraffin and 0.04% Co.; unfired; supplied by B. F. Drakenfeld Co.
8	835	Skinner, K.G.	1962	L	448-1323	NRL 199	Similar to the above specimen; except prepared in the above manner at Naval Research Laboratories.
9	835	Skinner, K.G.	1962	L	448-1448	TAM	Dry pressed at 10,000 psi using 2.5% paraffin and 0.04% Co; fired; hexagonal bar 0.65 cm between faces and 5.0 cm long; supplied by the Titanium Alloy Manufacturing Division, National Lead Co.
10	835	Skinner, K.G.	1962	L	448-1698	TAM CP 254	Similar to the above specimen except fired.
11	835	Skinner, K.G.	1962	L	448-1698	Drakenfeld	Similar to the above specimen except supplied by B. F. Drakenfeld Co.
12	835	Skinner, K.G.	1962	L	448-1398	NRL 205	Dry pressed at 10,000 psi using 2.5% paraffin and 0.04% Co; fired, hexagonal bar 0.65 cm between faces and 5.0 cm long; prepared in the Naval Research Laboratories.
13	836	Rhodes, R.G.	1951	X	113-293		Crystalline specimen; transitions observed at 174 K and 277 K; expansion measured along a-axis.
14	836	Rhodes, R.G.	1951	X	113-293		The above specimen; expansion measured along b-axis.
15	836	Rhodes, R.G.	1951	X	113-293		The above specimen; expansion measured along c-axis.
16	263	Bunting, E.N., Shelton, G.R., and Creamer, A.S.	1947	I	298-973	BT	Weighted batch constituents added to distilled water containing wetting agent in high-speed stirrer; caked mixture passed through No. 50 sieve and moistened with 10.0 of 2.5 starch suspension; calcined cylinder pressed from moist powder then pulverized, passed through No. 325 sieve, then moistened with 5.0 of 2.5 starch suspension, dry pressed at 20,000 psi into the form of disks 0.125 in. thick, diameter from 0.25 in. to 0.1 in.; mature temperature 1385 C held for 2 hr.

SPECIFICATION TABLE 141. THERMAL LINEAR EXPANSION OF BARIUM TITANIUM OXIDE $BaO \cdot TiO_2$ (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
17	837	Kimura, S. and Uchida, S.	1968		293-393	No. 3	Flame-sprayed specimen, 46 mm x 56 mm x 0.1 mm, heat treatment at 1200 C for 2 hr.
18*	837	Kimura, S. and Uchida, S.	1968		293-393	No. 4	Similar to the above specimen, heat treatment at 1400 C for 2 hr.
19*	837	Kimura, S. and Uchida, S.	1968		293-393	No. 7	Powder material.
20	837	Kimura, S. and Uchida, S.	1968		293-393	No. 9	Specimen, 46 mm x 56 mm x 0.1 mm, heat to 1450 C and quenched.
21*	838	Shintani, Y. and Tada, O.	1970	X	523-1473		99.36% pure powder $BaTiO_3$ films, deposited onto Pt sheet, assuming sputtered $BaTiO_3$ as cubic phase; lattice constant reported at 523 K is 4.091 Å; this curve is here reported using the first given temperature (523 K) as reference temperature at which $\Delta L/L_0 = 0$.
22	839	Miyake, S. and Ueda, R.	1948	X	293-445		Powder sample; expansion measured along a-axis.
23	840	Megaw, H.D.	1947	X	293-391		$BaTiO_3$ containing 1.5% silica fired at 1300 C to form sintered disk, cut ground, etched to rod about 2 cm long, 1 mm diameter, expansion of tetragonal phase along a-axis; 3.9946 Å reported at 293 K.
24	840	Megaw, H.D.	1947	X	293-391		The above specimen, expansion measured along c-axis; 4.0335 Å reported at 293 K.

* Not shown in figure.

DATA TABLE 141. THERMAL LINEAR EXPANSION OF BARIUM TITANIUM OXIDE $BaO \cdot TiO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
293	0.000
353	0.030
374	0.044
418	0.046
443	0.085
473	0.129
494	0.145
502	0.159
530	0.194
573	0.241
623	0.297
658	0.353
712	0.415
730	0.449

CURVE 2

T	$\Delta L/L_0$
293	0.000*
315	0.007
347	0.017*
373	0.031*
382	0.035
385	0.038*
390	0.040*
398	0.045*
405	0.046
413	0.050*
429	0.055*
436	0.057*
440	0.060
446	0.062*
452	0.064*
462	0.071*
464	0.075
470	0.079*
476	0.084*
481	0.090*
490	0.100
504	0.115
520	0.132
534	0.145*
545	0.159
558	0.173*
573	0.187
583	0.199*
595	0.215

CURVE 2 (cont.)

T	$\Delta L/L_0$
608	0.227*
621	0.241
645	0.267*
659	0.280
670	0.294*
680	0.308
695	0.322
707	0.334*
721	0.348
733	0.362*
749	0.376
765	0.390

CURVE 3

T	$\Delta L/L_0$
81	-0.132
112	-0.109
156	-0.077
177	-0.060
195	-0.061
218	-0.038
238	-0.022
253	-0.010
265	-0.012
273	-0.014
291	-0.001*
327	0.015
348	0.027*
375	0.046*

CURVE 4

T	$\Delta L/L_0$
366	0.023
422	0.041*
478	0.092
533	0.171
589	0.242
644	0.311
700	0.386
755	0.456
811	0.526
866	0.599
922	0.678
978	0.763

CURVE 5

T	$\Delta L/L_0$
348	0.039*
448	0.157
573	0.335
698	0.481
823	0.655
948	0.846
1073	1.037
1198	1.253
1323	1.203
1398	0.284

CURVE 6

T	$\Delta L/L_0$
348	0.087
448	0.193
573	0.336*
698	0.475*
823	0.643*
948	0.835*
1073	1.048*
1198	1.069
1323	0.720

CURVE 7

T	$\Delta L/L_0$
348	0.044
448	0.133
573	0.325*
698	0.475*
823	0.644*
948	0.842*
1073	1.019
1198	1.059*
1323	0.567

CURVE 8

T	$\Delta L/L_0$
448	0.140*
573	0.265
698	0.403
823	0.572
948	0.717
1073	0.856
1198	1.030
1323	0.679

CURVE 9

T	$\Delta L/L_0$
448	0.078*
573	0.168
698	0.429
823	0.588
948	0.774
1073	0.956
1198	1.133
1323	1.316
1448	1.492

CURVE 10

T	$\Delta L/L_0$
448	0.105
573	0.242*
698	0.396*
823	0.569*
948	0.723*
1073	0.906
1198	1.085
1323	1.260
1448	1.313
1573	1.402
1698	1.230

CURVE 11

T	$\Delta L/L_0$
448	0.089*
573	0.243*
698	0.388*
823	0.563*
948	0.739
1073	0.905*
1198	1.100
1323	1.310*
1448	1.477
1573	1.667
1698	1.694

CURVE 12

T	$\Delta L/L_0$
448	0.096*
573	0.247*
698	0.425*
823	0.615
948	0.808
1073	0.987

CURVE 12 (cont.)

T	$\Delta L/L_0$
1198	1.162
1323	1.344
1448	1.520

CURVE 13

T	$\Delta L/L_0$
113	-0.123
174	-0.076
277	-0.025
293	0.000*

CURVE 14

T	$\Delta L/L_0$
113	-0.365
174	-0.318
277	-0.025*
293	0.000*

CURVE 15

T	$\Delta L/L_0$
113	-0.051
174	-0.001
277	-0.010*
293	0.000*

CURVE 16

T	$\Delta L/L_0$
298	0.003*
373	0.053*
473	0.133*
573	0.253*
673	0.383
773	0.523
873	0.663
973	0.803

CURVE 17

T	$\Delta L/L_0$
293	0.000*
333	0.022
393	0.057

CURVE 18*

T	$\Delta L/L_0$
293	0.000
333	0.012
393	0.045

CURVE 19*

T	$\Delta L/L_0$
293	0.000
333	0.022
393	0.057

CURVE 20

T	$\Delta L/L_0$
293	0.000*
333	0.030*
393	0.075

CURVE 21*

T	$\Delta L/L_0$
523	0.000
572	-0.262
672	-0.262
773	-0.496
872	-0.980
1073	-1.481
1273	-1.960
1473	-1.960

CURVE 22

T	$\Delta L/L_0$
293	0.000*
323	0.020*
344	0.070
360	0.123
364	0.148
368	0.168
372	0.196
375	0.228
381	0.329
385	0.349
393	0.339
445	0.396

CURVE 23

T	$\Delta L/L_0$
293	0.000*
363	0.138
373	0.153
389	0.243
390	0.243
390.5	0.256*
391	0.276

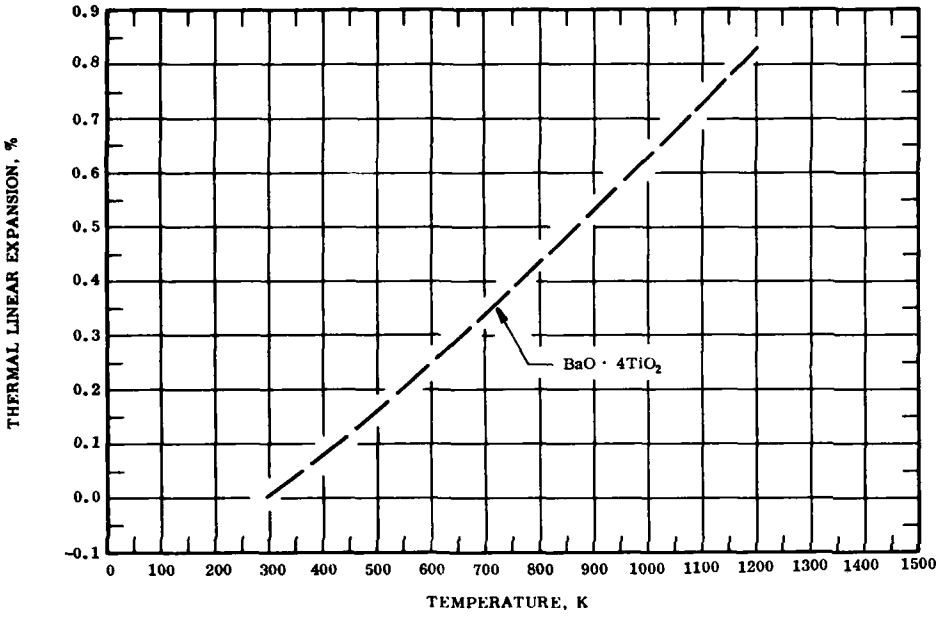
* Not shown in figure.

DATA TABLE 141. THERMAL LINEAR EXPANSION OF BARIUM TITANIUM OXIDE $BaO \cdot TiO_2$ (continued)

T	$\Delta L/L_0$
CURVE 24	
293	0.000*
363	-0.154
373	-0.228
389	-0.328
390	-0.377
390.5	-0.415
391	-0.425

* Not shown in figure.

FIGURE AND TABLE NO. 142R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF BARIUM TITANIUM OXIDES



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, $10^{-6}\ K^{-1}$]

T	$\Delta L/L_0$	α
293	0.000	7.4
350	0.043	7.7
400	0.082	7.9
500	0.164	8.4
600	0.249	8.7
700	0.338	9.1
800	0.431	9.4
900	0.527	9.7
1000	0.625	10.0
1100	0.726	10.2
1200	0.829	10.4

REMARKS

The provisional values are considered accurate to within ± 7% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.195 + 5.859 \times 10^{-4}\ T + 2.921 \times 10^{-7}\ T^2 - 5.724 \times 10^{-11}\ T^3$$

The tabulated values for the coefficient of thermal expansion are primarily derived by differentiating the above equation and are considered accurate to about ± 7%.

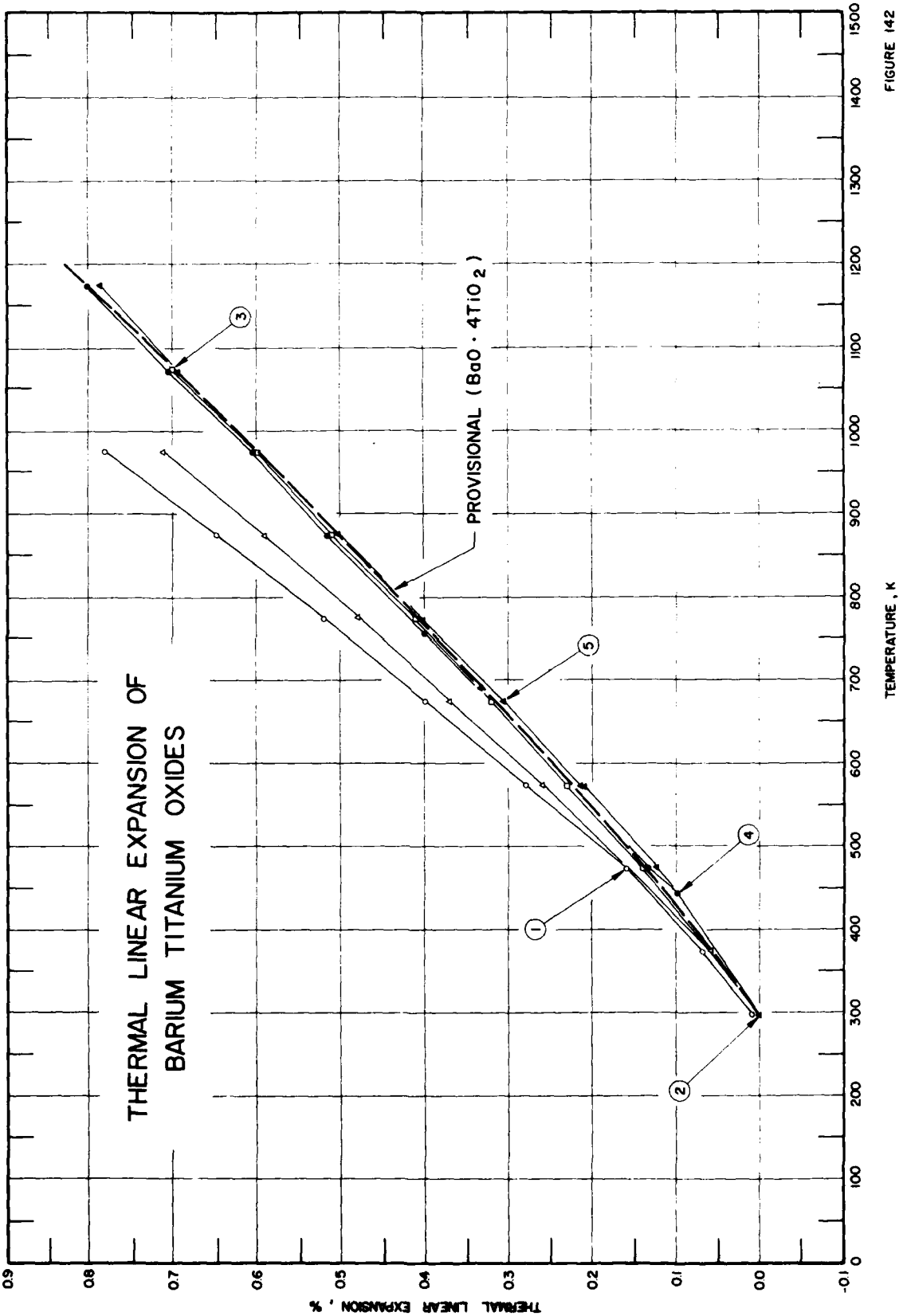

THERMAL LINEAR EXPANSION OF
BARIUM TITANIUM OXIDES
PROVISIONAL (BaO · 4TiO2)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1
2
3
4
5

FIGURE 142

SPECIFICATION TABLE 142. THERMAL LINEAR EXPANSION OF BARIUM TITANIUM OXIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	263	Bunting, E.N., Shelton, G.R., and Creamer, A.S.	1947	I	298-973	$BaO \cdot 2TiO_2$ (BT_2)	Barium titanium oxide; constituents mixed, powder pressed into cylinder, dried, heated at 1373 K for 1 hr, calcined cylinder pulverized, passed through No. 325 sieve, then moistened with starches, dry pressed at 20,000 psi into the form of disk, 0.125 in. thick, diameter from 0.25 in. to 1.0 in.; mature temperature 1563 K held for 1 hr; zero-point correction 0.01%.
2	263	Bunting, E.N., Shelton, G.R., and Creamer, A.S.	1947	I	298-973	$BaO \cdot 3TiO_2$ (BT_3)	Barium titanium oxide; constituents mixed, powder pressed into cylinder, dried, heated at 1373 K for 1 hr; calcined cylinder pulverized, passed through No. 325 sieve, then moistened with starch, dry pressed at 20,000 psi into the form of disk, 0.125 in. thick, diameter from 0.25 in. to 1.0 in.; mature temperature 1533 K held for 1 hr.
3	263	Bunting, E.N., Shelton, G.R., and Creamer, A.S.	1947	I	298-1073	$BaO \cdot 4TiO_2$ (BT_4)	Barium titanium oxide; constituents mixed, powder pressed into cylinder, dried, heated at 1373 K for 1 hr; calcined cylinder pulverized, passed through No. 325 sieve, then moistened with starch, dry pressed at 20,000 psi into the form of disk, 0.125 in. thick, diameter from 0.25 in. to 1.0 in.; mature temperature 1603 K held for 1 hr.
4	841	Readey, D.W., Maguire, E.A., Hartwig, C.P., Masse, D.J., and Paladino, A.E.	1970	L	444-1275	$BaO \cdot 4TiO_2$	Barium titanium oxide; no details given.
5	841	Readey, D.W., et al.	1970	L	444-1300	$BaO \cdot 4TiO_2$	Barium titanium oxide; similar to the above specimen.

DATA TABLE 142. THERMAL LINEAR EXPANSION OF BARIUM TITANIUM OXIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.01
373	0.07
473	0.16
573	0.28
673	0.40
773	0.52
873	0.65
973	0.78
CURVE 2	
298	0.00
373	0.06
473	0.16*
573	0.26

T	$\Delta L/L_0$
CURVE 2 (cont.)	
673	0.37
773	0.48
873	0.59
973	0.71
CURVE 3	
298	0.00*
373	0.06*
473	0.14
573	0.23
673	0.32
773	0.41
873	0.51
973	0.60
1073	0.70

T	$\Delta L/L_0$
CURVE 4	
444	0.100
474	0.135
673	0.318*
756	0.401
771	0.413*
874	0.514
974	0.603
1072	0.703
1173	0.800
1275	0.892
CURVE 5	
444	0.100*
474	0.126
573	0.210

T	$\Delta L/L_0$
CURVE 5 (cont.)	
573	0.214
673	0.307
689	0.332
771	0.404
874	0.505
1072	0.695
1173	0.786
1275	0.872
1300	0.900

* Not shown in figure.

SPECIFICATION TABLE 143. THERMAL LINEAR EXPANSION OF COBALT TITANIUM OXIDE $CoO \cdot TiO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	876	Kirchner, H.P., Graver, R.M., Platts, D.R., and Walker, R.F.	1967	L	307-1271		Commercial grade, obtained from Titanium Alloy Division of National Lead Company.

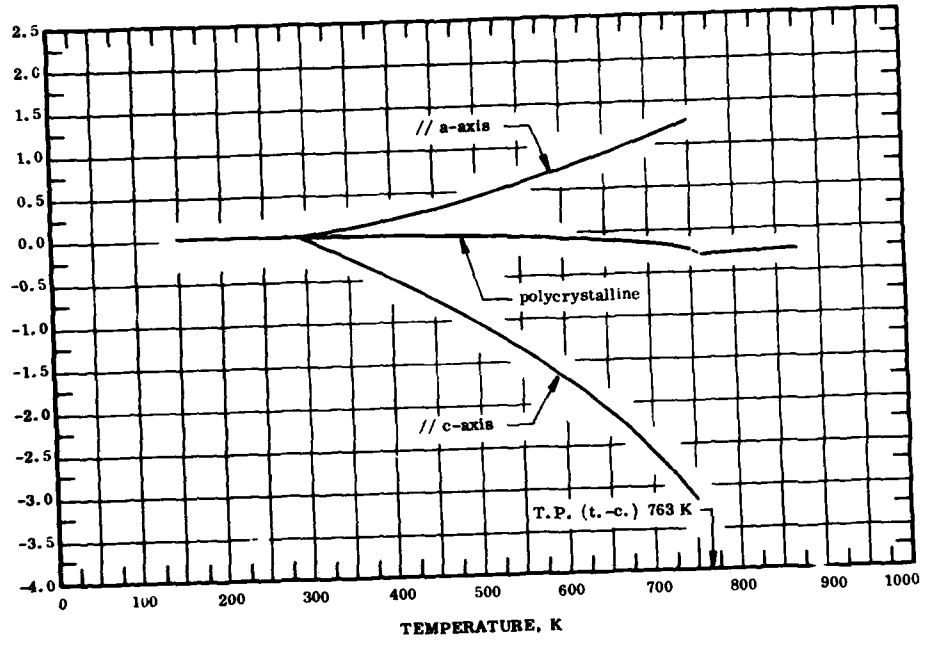
DATA TABLE 143. THERMAL LINEAR EXPANSION OF COBALT TITANIUM OXIDE $CoO \cdot TiO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
307	0.014
471	0.172
673	0.352
875	0.562
1071	0.777
1271	0.984

* No figure given.

FIGURE AND TABLE NO. 144R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF LEAD TITANIUM OXIDE $PbO \cdot TiO_2$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
150			0.007	0.3
200			0.009	0.1
250			0.004	-1.0
293	0.000	0.000	0.000	-3.3
350	0.104	-0.294	-0.029	-3.8
400	0.205	-0.542	-0.044	-2.4
450	0.315	-0.794	-0.054	-1.7
500	0.437	-1.063	-0.062	-1.8
550	0.570	-1.364	-0.074	-2.7
600	0.717	-1.710	-0.091	-4.4
650	0.878	-2.115	-0.119	-6.9
700	1.055	-2.592	-0.161	-10.2
750	1.249	-3.156	-0.221	-24.0
763†			-0.309	
800			-0.302	5.5
850			-0.278	5.5
875			*-0.261*	*5.5*

† Transition temperature.

REMARKS

The recommended values are based on the data for the pure sample and are considered accurate to within ± 5%. These values are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.415 + 1.228 \times 10^{-3} T + 2.161 \times 10^{-7} T^2 + 1.474 \times 10^{-9} T^3$

// c-axis: $\Delta L/L_0 = 2.477 - 1.307 \quad 10^{-2} T + 2.110 \times 10^{-5} T^2 - 1.826 \times 10^{-8} T^3$

polycrystalline: $\Delta L/L_0 = 0.551 - 3.571 \times 10^{-3} T + 7.284 \times 10^{-6} T^2 - 5.195 \times 10^{-9} T^3$ (293-750 K)

The tabulated values for the coefficient of thermal expansion are derived by differentiating the above equation and the more elaborate spline equations which are used to fit the percent thermal expansion data. These values are considered accurate to about ± 10%.

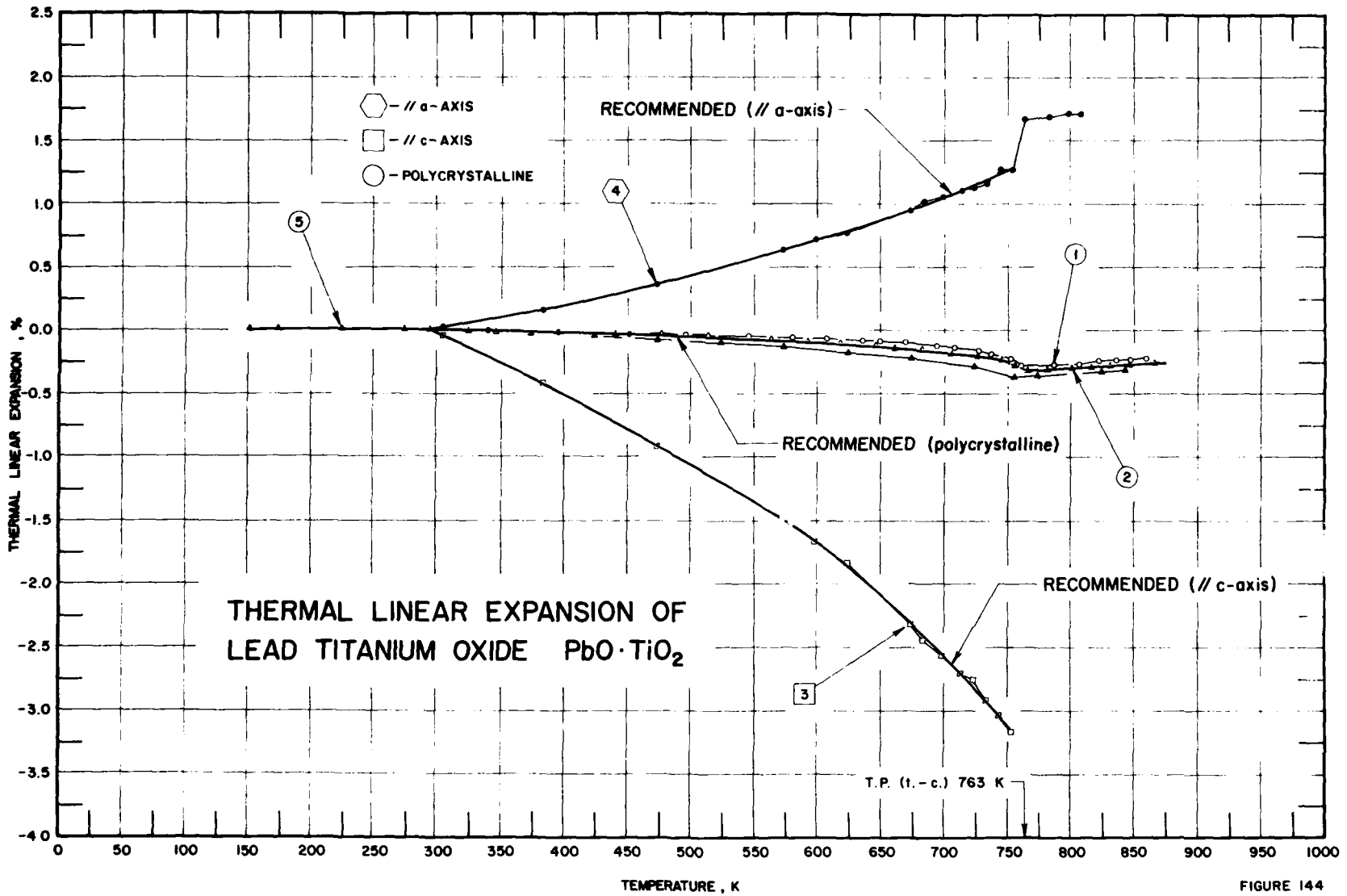

THERMAL LINEAR EXPANSION OF
LEAD TITANIUM OXIDE PbO·TiO2
⬡ – // a-AXIS
□ – // c-AXIS
○ – POLYCRYSTALLINE
RECOMMENDED (// a-axis)
RECOMMENDED (polycrystalline)
RECOMMENDED (// c-axis)
T.P. (t.-c.) 763 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 144

SPECIFICATION TABLE 144. THERMAL LINEAR EXPANSION OF LEAD TITANIUM OXIDE $PbO \cdot TiO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	877	Bhide, V.G., Hedge, M.S., and Deshmukh, K.G.	1968	I	338-858		Single crystal, started with mixture of $32PbTiO_3$-68KF; presintered $PbTiO_3$ placed in flat bottomed crucible and covered with KF; crucible placed in well-insulated furnace, temperature increased to 1030 C; during soaking period the nuclei formed and crystal growth started.
2	877	Bhide, V.G., et al.	1968	I	345-865		Similar to the above specimen.
3	878	Shirane, G. and Hoshino, S.	1951	X	303-753		Powdered specimen, expansion measured along c-axis; 4.140 Å reported at 303 K; 4.142 Å at 293 K determined by graphical extrapolation.
4	878	Shirane, G. and Hoshino, S.	1951	X	303-808		The above specimen, expansion measured along a-axis; 3.894 Å reported at 303 K; 3.893 Å at 293 K determined by graphical extrapolation.
5	878	Shirane, G. and Hoshino, S.	1951	L	151-842		Specimen formed into rod, 3 cm long, 0.3 cm diameter; zero-point correction -0.008%.

DATA TABLE 144. THERMAL LINEAR EXPANSION OF LEAD TITANIUM OXIDE $PbO \cdot TiO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 2 (cont.)		CURVE 3 (cont.)		CURVE 4 (cont.)		CURVE 5 (cont.)	
338	-0.010	821	-0.246	681	-0.157	573	-1.473	598	0.719	173	0.009
395	-0.021	835	-0.237	705	-0.176	598	-1.666	623	0.771	223	0.009
451	-0.029	846	-0.227	726	-0.197	623	-1.835	673	0.950	273	0.003
495	-0.039	859	-0.217	744	-0.248	673	-2.318	683	1.027	293	0.000
545	-0.050			755	-0.278	683	-2.438	698	1.053	323	-0.009
580	-0.060	CURVE 2		765	-0.318	698	-2.559	713	1.105	373	-0.025
607	-0.068			781	-0.309	713	-2.704	723	1.130	423	-0.047
635	-0.079	345	-0.010	800	-0.298	723	-2.752	733	1.156	473	-0.070
649	-0.089	394	-0.019*	815	-0.290	733	-2.921	743	1.259	523	-0.097
668	-0.098	440	-0.027	830	-0.277	743	-3.042	753	1.259	573	-0.131
693	-0.118	476	-0.039	845	-0.269	753	-3.163	763	1.669	623	-0.174
707	-0.137	513	-0.047	865	-0.258			783	1.695	673	-0.219
726	-0.158	543	-0.058*			CURVE 4		798	1.721	723	-0.292
736	-0.187	563	-0.069	CURVE 3				808	1.721	754	-0.372
751	-0.218	592	-0.089			303	0.026			773	-0.360
760	-0.279	617	-0.098	303	-0.048	383	0.154	CURVE 5		823	-0.325
786	-0.269	645	-0.117	383	-0.410	473	0.359			842	-0.308
806	-0.259	660	-0.139	473	-0.917	573	0.642	151	0.007		

* Not shown in figure.

SPECIFICATION TABLE 145. THERMAL LINEAR EXPANSION OF MAGNESIUM TITANIUM OXIDE $MgO \cdot 2TiO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	241	Thielke, N.R.	1954	X	323-1239	Magnesium dititanate	Expansion measured along a-axis; 9.7224 Å at 293 K determined by graphical extrapolation.
2*	241	Thielke, N.R.	1954	X	310-1273	Magnesium dititanate	Expansion measured along b-axis; 9.9841 Å at 293 K determined by graphical extrapolation.
3*	241	Thielke, N.R.	1954	X	323-1237	Magnesium dititanate	Expansion measured along c-axis; 3.7392 Å at 293 K determined by graphical extrapolation.

DATA TABLE 145. THERMAL LINEAR EXPANSION OF MAGNESIUM TITANIUM OXIDE $MgO \cdot 2TiO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*		CURVE 3*	
323	0.011	310	0.026	323	0.006
408	0.044	473	0.279	473	0.030
473	0.079	598	0.595	673	0.065
519	0.106	673	0.726	729	0.084
592	0.156	762	0.824	873	0.148
673	0.226	873	0.899	1073	0.273
747	0.319	984	0.959	1237	0.391
841	0.464	1073	1.018		
873	0.524	1146	1.086		
1073	0.899	1201	1.154		
1155	1.042	1273	1.242		
1239	1.139				

* No figure given.

SPECIFICATION TABLE 146. THERMAL LINEAR EXPANSION OF MAGNESIUM TITANIUM OXIDE $2MgO \cdot TiO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	307	McKinstry, H.A.	1949		299-1273		Bar specimen fired 2 hr at 1673 K.

DATA TABLE 146. THERMAL LINEAR EXPANSION OF MAGNESIUM TITANIUM OXIDE $2MgO \cdot TiO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
299	0.007
373	0.058
473	0.151
573	0.253
673	0.356
773	0.461
873	0.576
973	0.698
1073	0.822
1173	0.949
1273	1.067

* No figure given.

SPECIFICATION TABLE 147. THERMAL LINEAR EXPANSION OF NICKEL TITANIUM OXIDE $NiO \cdot TiO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	876	Kirchner, H. P., Gruver, R. M., Platts, D. R., and Walker, R. F.	1967	L	304-1267		Commercial grade; obtained from Titanium Alloy Division of National Lead Company.

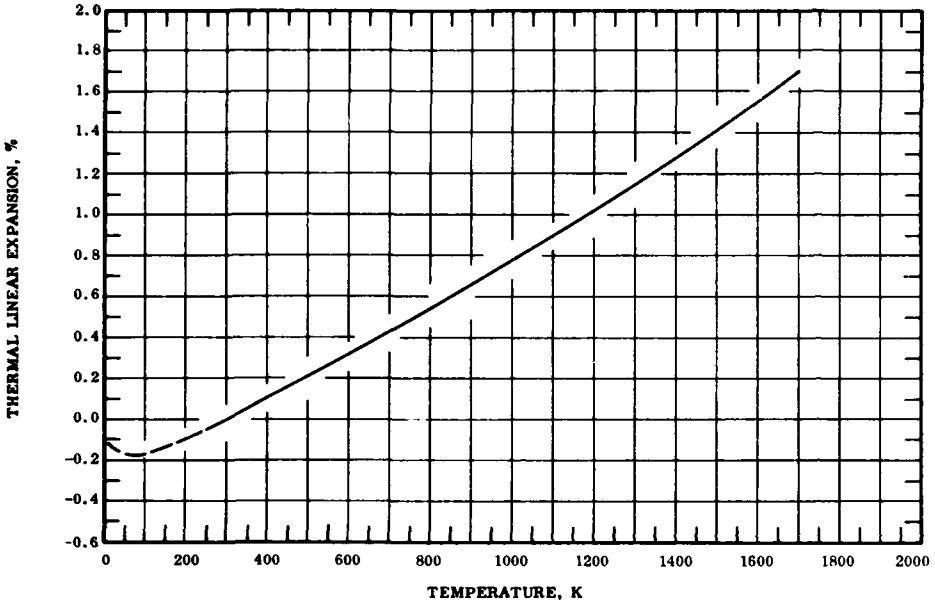
DATA TABLE 147. THERMAL LINEAR EXPANSION OF NICKEL TITANIUM OXIDE $NiO \cdot TiO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
304	0.009
473	0.154
673	0.344
873	0.549
1069	0.777
1267	1.025

* No figure given.

FIGURE AND TABLE NO. 148R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF STRONTIUM TITANIUM OXIDE $SrO \cdot TiO_2$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
10	-0.134†	-15.4
50	-0.171†	-5.1
100	-0.175†	3.3
120	-0.165†	5.8
140	-0.152†	7.7
150	-0.143†	8.3
160	-0.134†	8.8
170	-0.125†	9.3
180	-0.115†	9.7
190	-0.104†	10.0
200	-0.093†	10.1
250	-0.039†	10.2
293	0.000	10.3
400	0.106	10.4
500	0.212	10.6
600	0.320	10.9
700	0.430	11.2
800	0.545	11.4
900	0.660	11.7
1000	0.780	12.0
1100	0.900	12.3
1200	1.025	12.6
1300	1.152	13.0
1400	1.283	13.3
1500	1.420	13.6
1600	1.555	14.0
1700	1.700	14.4

† Provisional values.

REMARKS

The recommended values are based on the data for pure sample and are considered accurate to within ±5% at temperatures above 293 K and ±10% below 293 K. These values are represented approximately by the following equations:

$$\Delta L/L_0 = -0.119 - 1.653 \times 10^{-3} + 1.297 \times 10^{-5} T^2 - 2.032 \times 10^{-8} T^3 \quad (10\text{-}293\ K)$$

$$\Delta L/L_0 = -0.292 + 9.580 \times 10^{-4} T + 9.252 \times 10^{-8} T^2 + 1.923 \times 10^{-11} T^3 \quad (293\text{-}1700\ K)$$

The tabulated values for the coefficient of thermal expansion are derived from the experimental data and the values obtained by differentiating the above equations. These values are considered accurate to about ±10%.

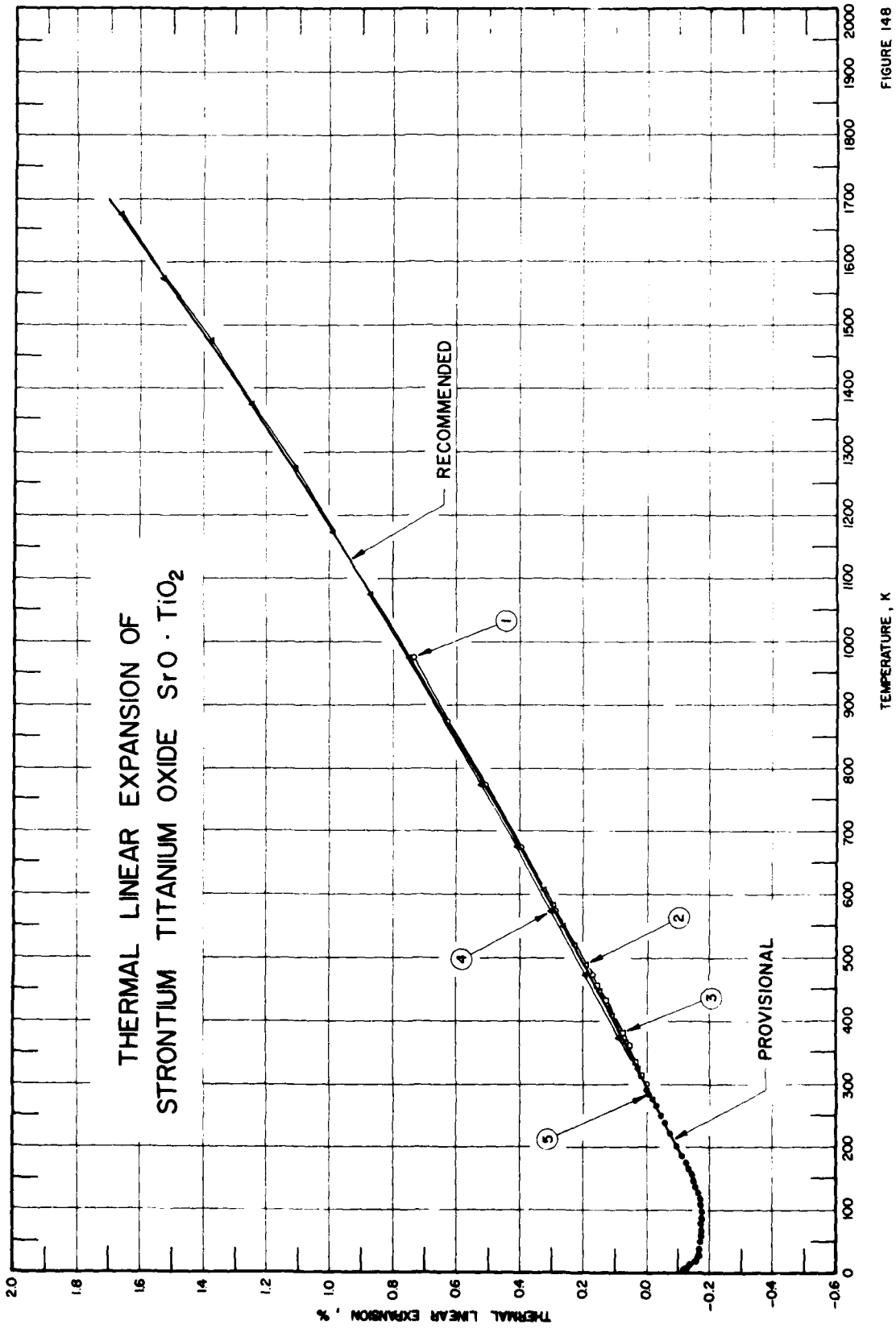

THERMAL LINEAR EXPANSION OF
STRONTIUM TITANIUM OXIDE SrO · TiO2
RECOMMENDED
PROVISIONAL
1
2
3
4
5
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 148

SPECIFICATION TABLE 148. THERMAL LINEAR EXPANSION OF STRONTIUM TITANIUM OXIDE $SrO \cdot TiO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	263	Bunting, E.N., Shelton, G.R., and Creamer, A.S.	1947	I	298-973	ST	Weighted batch constituents mixed in a stirrer, sifted, moistened to make powder; pressed into cylinder, dried, heated at 1200 C for 1 hr; calcined cylinder pulverized, passed through a No. 325 sieve, then moistened with starch, dry pressed at 20,000 psi into the form of disk, 0.125 in. thick, diameter about 1.0 in.; mature temperature 1375 C held for 2 hr.
2	879	Devonarayanan, S. and Narayanan, P.S.	1968	I	325-608		Specimens cut from almost colorless boule furnished by National Lead Co., New Jersey; pyramid-shaped specimens; interference fringes observed visually during expansion.
3	879	Devonarayanan, S. and Narayanan, P.S.	1968	I	313-458		The above specimen; interference fringes recorded electronically.
4	194	Rimshaw, S.J. and Ketchen, E.E.	1969	L	273-1673		Hot pressed specimen containing 5% excess TiO_2; 3.7% Co, 3.7% Ba, and 0.3% Mg added to Sr before preparing specimen; experiment originally reported by E. Lamb in ORNL-4045.
5	880	Lytle, F.W.	1964	X	5-296		Specimen prepared from thin 1 mm plate cut from oriented single-crystal boule obtained from National Lead Company; unit cell parameter 3.90484 Å reported at 293 K.

DATA TABLE 148. THERMAL LINEAR EXPANSION OF STRONTIUM TITANIUM OXIDE $SrO \cdot TiO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.00
373	0.07
473	0.17
573	0.29
673	0.40
773	0.51
873	0.63
973	0.74
CURVE 2‡	
325	0.028
368	0.065
409	0.105
448	0.146
489	0.191
520	0.226
551	0.262
582	0.297
608	0.325
CURVE 3‡	
313	0.016
336	0.035
361	0.056
381	0.076
408	0.103*
433	0.129
458	0.155
CURVE 4	
273	-0.022
373	0.086
473	0.193
573	0.300
673	0.410
773	0.523
873	0.638*
973	0.755
1073	0.874
1173	0.994
CURVE 4 (cont.)	
1273	1.117
1373	1.253
1473	1.381
1573	11.536
1673	1.670
CURVE 5	
5	-0.115
6	-0.083*
7	-0.093*
8	-0.108*
10	-0.123
12	-0.147*
13	-0.144*
16	-0.138
17	-0.162*
20	-0.159
22	-0.150*
24	-0.157*
CURVE 5 (cont.)	
26	-0.160*
30	-0.162
33	-0.164*
37	-0.165*
40	-0.167
46	-0.168*
50	-0.169
56	-0.171*
60	-0.172
63	-0.173*
69	-0.174
76	-0.175*
80	-0.176
83	-0.177*
88	-0.174
94	-0.175*
97	-0.177*
100	-0.177
104	-0.177*
110	-0.172
CURVE 5 (cont.)	
114	-0.174*
116	-0.169*
119	-0.169
124	-0.165*
129	-0.162
135	-0.154*
138	-0.155
145	-0.147*
148	-0.145
155	-0.143*
158	-0.144
164	-0.135*
167	-0.131
173	-0.127*
175	-0.128
176	-0.123*
187	-0.111
196	-0.104*
201	-0.098
207	-0.092*
CURVE 5 (cont.)	
222	-0.007
227	-0.071*
239	-0.058
247	-0.046*
250	-0.048
252	-0.045*
266	-0.029
274	-0.021*
275	-0.021*
288	-0.005
293	0.000
296	0.004*

DATA TABLE 148. COEFFICIENT OF THERMAL LINEAR EXPANSION OF STRONTIUM TITANIUM OXIDE $SrO \cdot TiO_2$

[Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\ K^{-1}$]

T	α
CURVE 2*, ‡	
325	8.11
368	9.21
409	10.31
448	10.96
489	10.64
520	12.00
551	11.42
582	11.04
608	11.04
CURVE 3*, ‡	
313	7.98
336	8.17
361	9.22
381	10.34
408	9.95
433	10.75
458	10.08

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

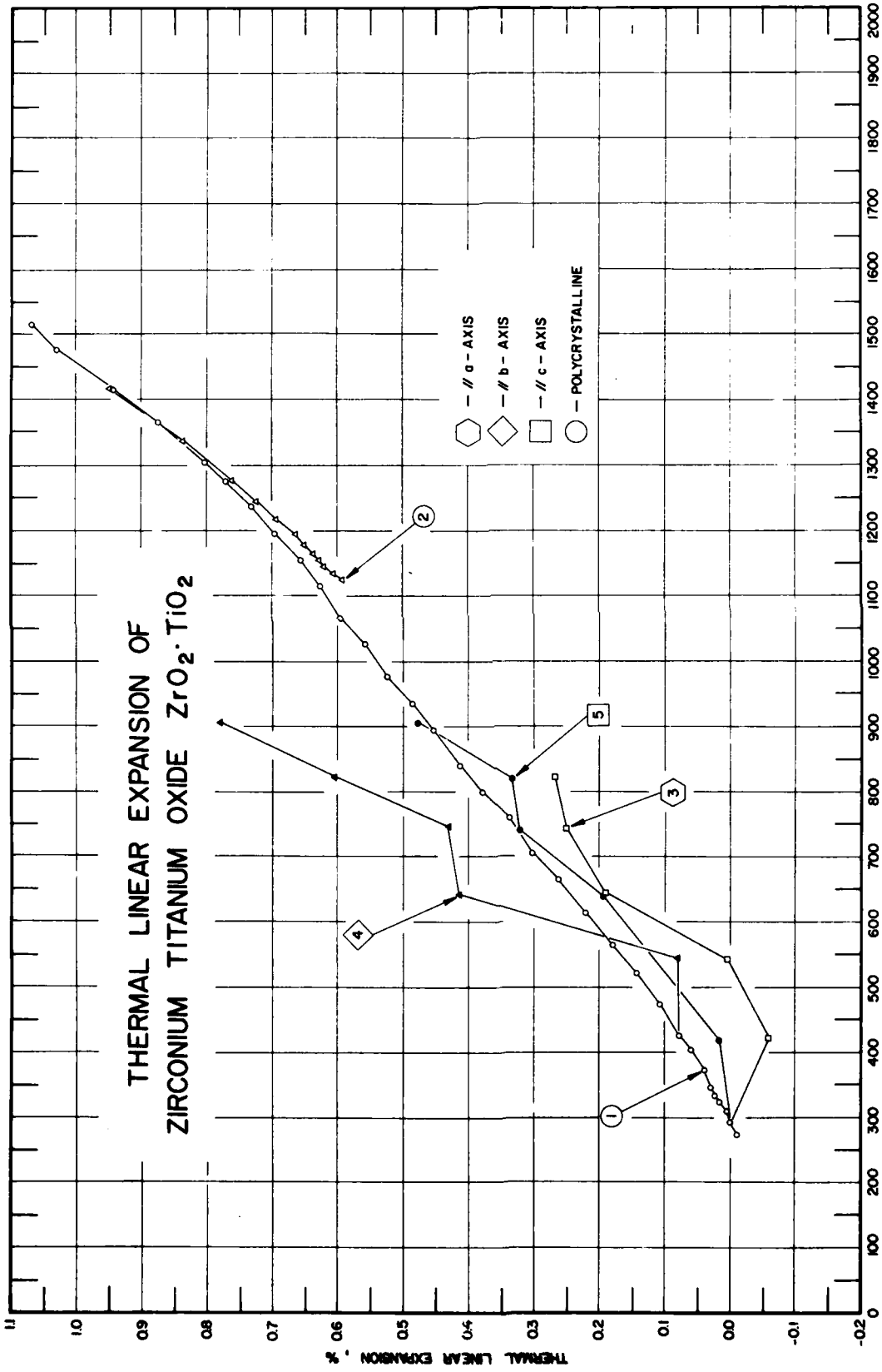

THERMAL LINEAR EXPANSION OF
ZIRCONIUM TITANIUM OXIDE $ZrO_2 \cdot TiO_2$
// a - AXIS
// b - AXIS
// c - AXIS
POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
4
5

FIGURE 149

SPECIFICATION TABLE 149. THERMAL LINEAR EXPANSION OF ZIRCONIUM TITANIUM OXIDE $ZrO_2 \cdot TiO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	10	Mauer, F.A. and Bolz, L.N.	1957	L	273-1515		Prepared by B.C. Weber of the Wright Air Development Center; specimen in form of tube.
2	10	Mauer, F.A. and Bolz, L.N.	1957	L	1417-1123		The above specimen; expansion with decreasing temperature.
3	881	Lynch, R.W. and Morosin, B.	1972	X	293-822		Orthorhombic compound prepared from chemically pure ZrO_2 (2% Hf) and high-purity TiO_2 (<0.1% Hf, <0.1% Zr); quenched and cooled slowly from 1573 K; expansion measured along a-axis.
4	881	Lynch, R.W. and Morosin, B.	1972	X	293-906		The above specimen; expansion measured along b-axis.
5	881	Lynch, R.W. and Morosin, B.	1972	X	293-905		The above specimen; expansion measured along c-axis.

DATA TABLE 149. THERMAL LINEAR EXPANSION OF ZIRCONIUM TITANIUM OXIDE $ZrO_2 \cdot TiO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 2		CURVE 3		CURVE 5	
273	-0.011	839	0.413	1417	0.950	293	0.000*	293	0.000*
293	0.000	393	0.454	1336	0.838	422	-0.060	419	0.016
309	0.004	933	0.486	1277	0.766	542	0.004	639	0.192
323	0.017	975	0.525	1243	0.726	642	0.191	741	0.322
333	0.023	1026	0.559	1216	0.694	743	0.250	820	0.333
347	0.030	1067	0.595	1193	0.665	822	0.268	905	0.478
373	0.039	1113	0.627	1178	0.651				
403	0.059	1153	0.657	1163	0.637	CURVE 4			
426	0.079	1195	0.696	1153	0.628				
475	0.108	1237	0.732	1145	0.621	293	0.000*		
522	0.143	1275	0.771	1137	0.613*	422	0.081*		
565	0.180	1303	0.803	1133	0.607	545	0.081		
613	0.221	1365	0.875	1131	0.604*	641	0.414		
663	0.263	1413	0.946	1129	0.602*	747	0.431		
705	0.302	1477	1.030	1125	0.599*	822	0.607		
760	0.338	1515	1.070	1124	0.593*	906	0.781		
800	0.379			1123	0.592				
839	0.413								

* Not shown in figure.

SPECIFICATION TABLE 150. THERMAL LINEAR EXPANSION OF ALUMINUM TUNGSTEN OXIDE $2Al_2O_3 \cdot 5WO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	883	Naitinek, C. and Hummel, F.A.	1968	L	302-973		Bar specimen 1 x 1 x 10 cm; pressed at 1000 psi to size, fired on platinum foil; heating at rate of 200 C per hr.

DATA TABLE 150. THERMAL LINEAR EXPANSION OF ALUMINUM TUNGSTEN OXIDE $2Al_2O_3 \cdot 5WO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
302	0.00
323	0.00
376	0.00
423	0.01
473	0.02
523	0.03
573	0.03
623	0.05
673	0.06
723	0.07
773	0.08
823	0.09
873	0.11
923	0.11
973	0.13

* No figure given.

SPECIFICATION TABLE 151. THERMAL LINEAR EXPANSION OF BARIUM CALCIUM TUNGSTEN OXIDE $2BaO \cdot CaO \cdot WO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	921	Graf, R.H.	1967	X	314-1338		Reagent grade alkaline earth carbonates from Mallinkodt Chemical Works; ground and mixed in mortar, pressed at 1200 psi, fired in air 2 hr at 1200 C, cooled, crushed, fired 2 hr at 1400 C; expansion measured using $CuK\alpha$ x-rays, (400) reflection observed; 2.0930 is reported at 314 K.
2*	921	Graf, R.H.	1967	X	312-1332		The above specimen except (422) reflection observed; 1.0078 Å reported at 312 K.
3*	921	Graf, R.H.	1967	X	301-1336		The above specimen except (440) reflection observed; 1.4809 Å reported at 301 K.
4*	921	Graf, R.H.	1967	X	307-1334		The above specimen except (531) reflection observed; 1.4163 Å reported at 307 K.
5*	921	Graf, R.H.	1967	X	308-1345		The above specimen except (620) reflection observed; 1.3244 Å reported at 307 K.
6*	921	Graf, R.H.	1967	X	304-1344		The above specimen except (444) reflection observed; 1.2041 Å reported at 304 K.
7*	921	Graf, R.H.	1967	X	303-1344		The above specimen except (642) reflection observed; 1.1175 Å reported at 303 K.
8*	921	Graf, R.H.	1967	X	302-1342		The above specimen except (840) reflection observed; 0.9360 Å reported at 302 K.

DATA TABLE 151. THERMAL LINEAR EXPANSION OF BARIUM CALCIUM TUNGSTEN OXIDE $2BaO \cdot CaO \cdot WO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 3*		CURVE 5*		CURVE 7*	
314	0.020	301	0.008	308	0.015	303	0.009
708	0.403	702	0.427	710	0.430	710	0.501
880	0.599	878	0.542	888	0.521	878	0.895
1338	1.000	1336	0.954	1345	0.800	1344	1.289
CURVE 2*		CURVE 4*		CURVE 6*		CURVE 8*	
312	0.036	307	0.013	304	0.017	302	0.011
709	0.790	704	0.395	709	0.681	702	0.449
861	1.128	878	0.592	884	0.822	876	0.641
1332	1.972	1334	1.115	1344	1.387	1342	1.122

* No figure given.

SPECIFICATION TABLE 152. THERMAL LINEAR EXPANSION OF BARIUM STRONTIUM TUNGSTEN OXIDE $2BaO \cdot SrO \cdot WO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	921	Graf, R.H.	1967	X	301-1023		Reagent grade alkaline earth carbonates from Mallinkrodt Chemical Works ground and mixed in mortar; pressed at 1200 psi, fired in air 2 hr at 1200 C, cooled, crushed, fired 2 hr at 1400 C; expansion measured using CuKα x-rays, (400) reflection observed, 2.1405 Å reported at 301 K.
2*	921	Graf, R.H.	1967	X	311-1178		The above specimen; 1.9600 Å reported at 311 K.
3*	921	Graf, R.H.	1967	X	307-1182		The above specimen except (442) reflection observed; 1.7445 Å reported at 307 K.
4*	921	Graf, R.H.	1967	X	310-1180		The above specimen except (440) reflection observed; 1.5104 Å reported at 310 K.
5*	921	Graf, R.H.	1967	X	303-1169		The above specimen except (642) reflection observed; 1.1445 Å reported at 303 K.
6*	921	Graf, R.H.	1967	X	314-1191		The above specimen except (620) reflection observed; 1.3522 Å reported at 314 K.
7*	921	Graf, R.H.	1967	X	307-1181		The above specimen except (840) reflection observed; 0.9574 Å reported at 307 K.
8*	921	Graf, R.H.	1967	X	303-1179		The above specimen except (731/553) reflection observed: 1.1217 Å reported at at 303 K.
9*	921	Graf, R.H.	1967	X	309-1187		The above specimen except (660/822) reflection observed; 1.0080 Å reported at 309 K.
10*	921	Graf, R.H.	1967	X	308-1182		The above specimen except (664) reflection observed; 0.9144 Å reported at 308 K.
11*	921	Graf, R.H.	1967	X	301-1182		The above specimen except (844) reflection observed; 0.8771 Å reported at 301 K.

* No figure given.

DATA TABLE 152. THERMAL LINEAR EXPANSION OF BARIUM STRONTIUM TUNGSTEN OXIDE $2BaO \cdot SrO \cdot WO_3$

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %)

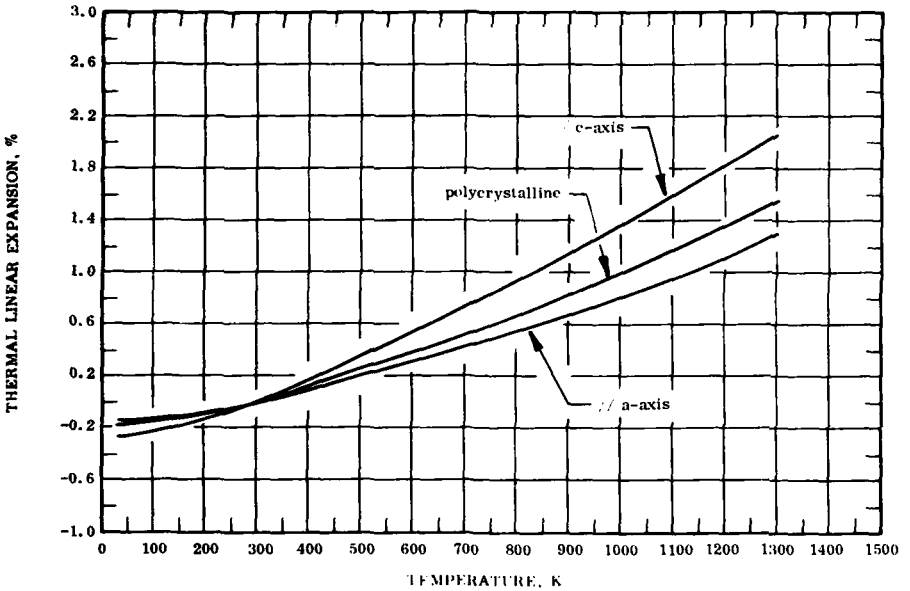
T	$\Delta L/L_0$
CURVE 1*	
301	0.001
530	0.265
777	0.443
825	0.151
906	0.214
1023	0.226
CURVE 2*	
311	0.026
537	0.349
782	0.521
831	0.621
910	0.621
1032	0.661
1178	0.766
CURVE 3*	
307	0.036
536	0.631
781	0.940
836	1.049
917	1.061
1028	1.061
1182	1.061
CURVE 4*	
310	0.040
531	0.517
780	0.881
830	1.013
908	1.007
1029	1.027
1180	1.080
CURVE 5*	
303	0.017
524	0.376
773	0.419
825	0.647
899	0.708
1026	0.804
1169	0.883

T	$\Delta L/L_0$
CURVE 6*	
314	0.044
533	0.481
791	0.792
838	0.895
913	0.910
1037	0.954
1191	1.021
CURVE 7*	
307	0.010
526	0.094
833	0.272
904	0.470
1029	0.564
1181	0.773
CURVE 8*	
303	0.006
524	0.146
783	0.176
839	0.242
1017	0.286
1179	0.328
CURVE 9*	
309	0.001
538	0.218
593	0.218
787	0.546
838	0.605
910	0.605
1041	0.645
1187	0.724
CURVE 10*	
308	0.004
534	0.071
582	0.098
781	0.152
833	0.261
908	0.302
1030	0.385
1182	0.515

T	$\Delta L/L_0$
CURVE 11*	
301	0.0023
522	0.0696
775	0.236
902	0.287
1026	0.326
1182	0.375

* No figure given.

FIGURE AND TABLE NO. 153R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF CALCIUM TUNGSTEN OXIDE $CaO \cdot WO_3$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
30	-0.275	-0.160	-0.198	0.2
40	-0.273	-0.159	-0.197	0.9
50	-0.271	-0.159	-0.196	1.7
60	-0.268	-0.157	-0.194	2.4
70	-0.264	-0.155	-0.191	3.1
80	-0.259	-0.153	-0.188	3.8
90	-0.253	-0.150	-0.184	4.4
100	-0.246	-0.146	-0.179	5.0
120	-0.230	-0.137	-0.168	6.2
140	-0.211	-0.126	-0.154	7.3
160	-0.189	-0.113	-0.138	8.2
180	-0.165	-0.099	-0.121	9.1
200	-0.140	-0.084	-0.103	9.8
220	-0.112	-0.067	-0.082	10.5
240	-0.084	-0.050	-0.061	11.0
260	-0.054	-0.032	-0.039	11.5
280	-0.020	-0.010	-0.013	11.7
293	0.000	0.000	0.000	11.8
350	0.097	0.051	0.067	11.9
400	0.180	0.100	0.127	12.2
500	0.355	0.203	0.253	13.0
600	0.578	0.311	0.387	13.8
700	0.725	0.425	0.525	14.6
800	0.940	0.550	0.680	15.5
900	1.166	0.680	0.840	16.4
1000	1.382	0.820	1.007	17.3
1100	1.620	0.960	1.180	18.3
1200	1.866	1.125	1.370	19.3
1300	2.123	1.300	1.571	20.3

REMARKS

The recommended values for the axial thermal expansion are based on the data for pure sample. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ±5% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -0.273 - 2.371 \times 10^{-4} T + 5.620 \times 10^{-6} T^2 - 5.582 \times 10^{-9} T^3$ (30-293 K)

$\Delta L/L_0 = -0.407 + 1.243 \times 10^{-3} T + 5.627 \times 10^{-7} T^2 - 1.698 \times 10^{-11} T^3$ (293-1300 K)

// a-axis: $\Delta L/L_0 = -0.156 - 2.338 \times 10^{-4} T + 3.715 \times 10^{-6} T^2 - 3.725 \times 10^{-9} T^3$ (30-293 K)

$\Delta L/L_0 = -0.262 + 8.370 \times 10^{-4} T + 1.279 \times 10^{-7} T^2 + 1.150 \times 10^{-10} T^3$ (293-1300 K)

polycrystalline: $\Delta L/L_0 = -0.195 - 2.299 \times 10^{-4} T + 4.305 \times 10^{-6} T^2 - 4.241 \times 10^{-9} T^3$ (30-293 K)

$\Delta L/L_0 = -0.309 + 9.685 \times 10^{-4} T + 2.790 \times 10^{-7} T^2 + 6.809 \times 10^{-11} T^3$ (293-1300 K)

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equations and are considered accurate to about ±7%.

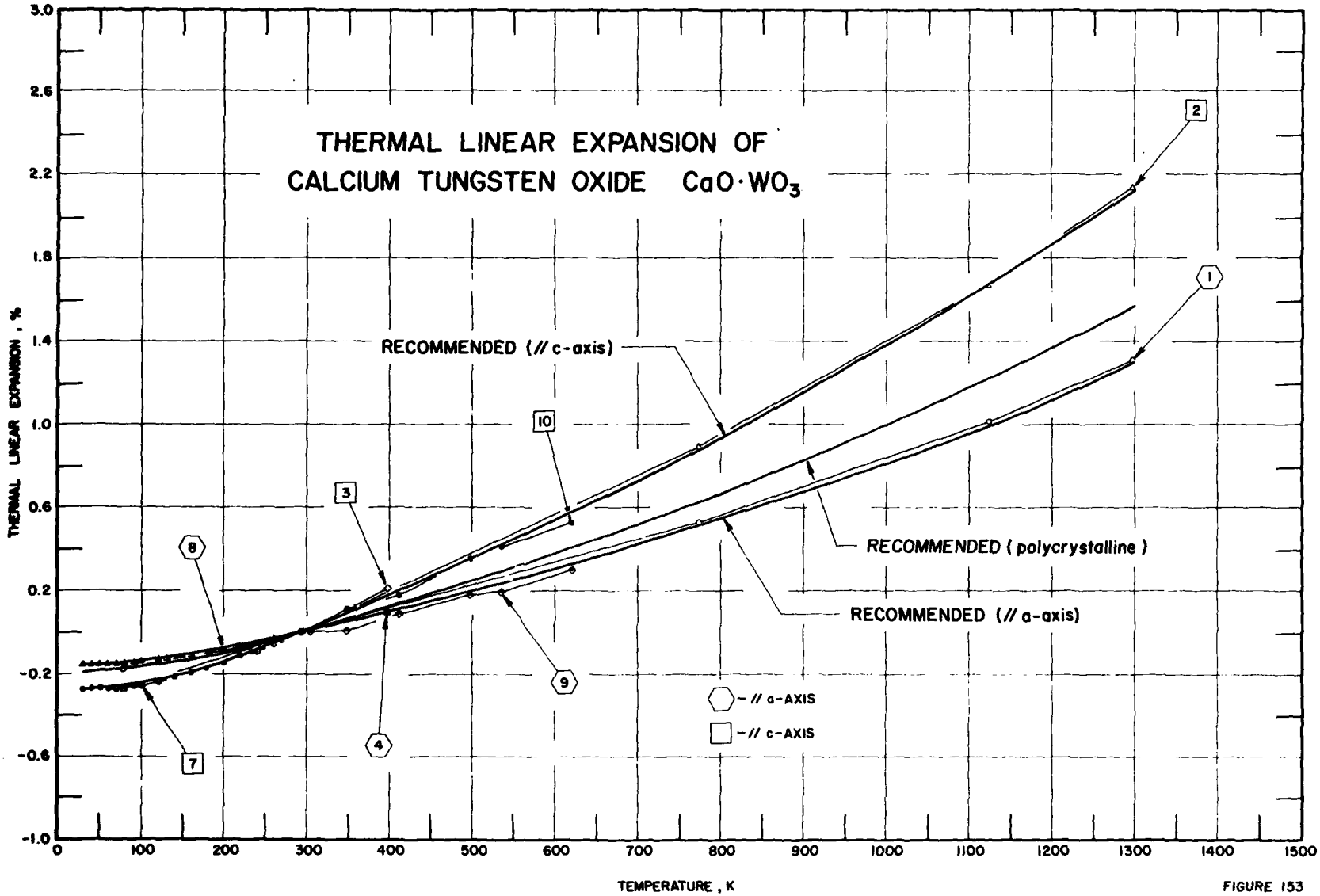

THERMAL LINEAR EXPANSION OF
CALCIUM TUNGSTEN OXIDE CaO·WO3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED (// c-axis)
RECOMMENDED (polycrystalline)
RECOMMENDED (// a-axis)
- // a-AXIS
- // c-AXIS
1
2
3
4
7
8
9
10
3.0
2.6
2.2
1.8
1.4
1.0
0.6
0.2
-0.2
-0.6
-1.0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 153

SPECIFICATION TABLE 153. THERMAL LINEAR EXPANSION OF CALCIUM TUNGSTEN OXIDE $CaO \cdot WO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	922	Nassau, K. and Broyer, A.M.	1962	I	79-1298		Specimen obtained as "fluorescent grade" material, prepared by precipitation from solution of reagent grade nitrates or chloride with sodium tungstate solution and by growth from sodium ditungstate flux; expansion measured along a-axis.
2	922	Nassau, K. and Broyer, A.M.	1962	I	79-1298		The above specimen; expansion measured along c-axis.
3	923	Morozov, A.M. and Selezneva, A.M.	1969	I	293, 398		Pure crystal grown by pulling from melt; expansion measured parallel to c-axis.
4	923	Morozov, A.M. and Selezneva, A.M.	1969	I	293, 398		The above specimen; expansion measured perpendicular to c-axis.
5*	923	Morozov, A.M. and Selezneva, A.M.	1969	I	293, 398		Similar to the above specimen; expansion measured parallel to c-axis.
6*	923	Morozov, A.M. and Selezneva, A.M.	1969	I	293, 398		The above specimen; expansion perpendicular to c-axis.
7	924	Yates, B. and Bailey, A.C.	1971	I	30-270		Single crystal specimen; impurity concentration of few parts per million; supplied by GECAEI; shape of small pyramid, approximately 7×10^{-3} m high; expansion measured parallel to c crystallographic axis.
8	924	Yates, B. and Bailey, A.C.	1971	I	30-270		The above specimen; expansion measured perpendicular to c crystallographic axis.
9	925	Deshpande, V.T. and Suryanarayana, S.V.	1972	X	303-620		The x-ray powder photographs at six different temperatures were taken employing a high temperature symmetrical focusing camera and CuK radiation; lattice parameter measured along a-axis; 5.2437 Å reported at 303 K.
10	925	Deshpande, V.T. and Suryanarayana, S.V.	1972	X	303-620		The above specimen; lattice parameter measured along c-axis; 11.3754 Å reported at 303 K.

* Not shown in figure.

DATA TABLE 153. THERMAL LINEAR EXPANSION OF CALCIUM TUNGSTEN OXIDE $CaO \cdot WO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
79	-0.170
298	0.004
773	0.536
1123	1.019
1298	1.313
CURVE 2	
79	-0.274
298	0.006*
773	0.895
1123	1.665
1298	2.141
CURVE 3	
293	0.000
398	0.205
CURVE 4	
293	0.000
398	0.124
CURVE 5*	
293	0.000
398	0.221
CURVE 6*	
293	0.000
398	0.134
CURVE 7‡	
30	-0.275
40	-0.273
50	-0.271
60	-0.268
70	-0.264
80	-0.259
90	-0.253
100	-0.246
120	-0.230
CURVE 7 (cont.)‡	
140	-0.211
160	-0.189
180	-0.165
200	-0.140
220	-0.112
240	-0.084
260	-0.054
270	-0.039
CURVE 8‡	
30	-0.160
40	-0.159
50	-0.159
60	-0.157
70	-0.155
80	-0.153
90	-0.150
100	-0.146
120	-0.137
140	-0.126
160	-0.113
180	-0.099
200	-0.084
220	-0.067
240	-0.050
260	-0.032
270	-0.023*
CURVE 9	
303	00.002
348	0.013
411	0.089
498	0.185
536	0.198
620	0.290
CURVE 10	
303	0.021*
348	0.117
411	0.180
498	0.350
536	0.423
620	0.533

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 154. THERMAL LINEAR EXPANSION OF CALCIUM MAGNESIUM TUNGSTEN OXIDE $2CaO \cdot MgO \cdot WO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	921	Graf, R.H.	1967	X	308-1482		Reagent grade alkaline earth carbonates from Mallinkrodt Chemical Works; ground and mixed in mortar, pressed at 1200 psi, fired in air 2 hr at 1200 C, cooled, crushed, fired 2 hr at 1400 C; expansion measured using CuKα x-rays, (400) reflection observed; 2.2186 Å reported at 308 K.
2*	921	Graf, R.H.	1967	X	307-1388		The above specimen, (400) reflection observed; 1.9229 Å reported at 307 K.
3*	921	Graf, R.H.	1967	X	306-1474		The above specimen, (331) reflection observed; 1.7391 Å reported at 306 K.
4*	921	Graf, R.H.	1967	X	305-1477		The above specimen, (422) reflection observed; 1.5686 Å reported at 305 K.
5*	921	Graf, R.H.	1967	X	301-1476		The above specimen, (511/333) reflection observed; 1.4689 Å reported at 301 K.
6*	921	Graf, R.H.	1967	X	296-1470		The above specimen, (440) reflection observed; 1.3575 Å reported at 296 K.
7*	921	Graf, R.H.	1967	X	293-1363		The above specimen, (444) reflection observed; 1.1211 Å reported at 293 K.
8*	921	Graf, R.H.	1967	X	305-1470		The above specimen, (551/711) reflection observed; 1.0807 Å reported at 305 K.
9*	921	Graf, R.H.	1967	X	305-1477		The above specimen, (642) reflection observed; 1.0413 Å reported at 305 K.
10*	921	Graf, R.H.	1967	X	303-1388		The above specimen, (731/553) reflection observed; 1.0060 Å reported at 303 K.
11*	921	Graf, R.H.	1967	X	301-1480		The above specimen, (800) reflection observed; 0.9637 Å reported at 301 K.

* No figure given.

DATA TABLE 154. THERMAL LINEAR EXPANSION OF CALCIUM MAGNESIUM TUNGSTEN OXIDE $2CaO \cdot MgO \cdot WO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
308	0.000
593	0.005
806	-0.437
1094	-0.599
1206	-0.451
1280	-0.690
1395	-0.663
1482	-0.816
CURVE 2*	
307	-0.018
593	-0.387
807	-0.808
1094	-0.933
1388	-1.193
CURVE 3*	
306	0.033
588	0.758
807	1.069
1094	1.138
1153	1.581
1278	1.241
1378	1.696
1474	1.805
CURVE 4*	
305	0.029
584	0.705
806	0.514
1075	0.086
1144	0.884
1273	0.335
1383	0.935
1477	0.718
CURVE 5*	
301	0.011
587	0.385
798	0.991
1148	1.270
1271	1.366
1380	1.672
1476	1.529
CURVE 6*	
296	0.010
576	0.990
802	1.874
1092	2.176
1145	2.103
1276	2.935
1366	3.245
1470	3.422
CURVE 7*	
293	0.000
572	0.232
802	1.436
1084	1.873
1137	1.873
1363	2.328
CURVE 8*	
305	0.006
577	0.145
805	1.274
1088	0.802
1140	1.292
1272	1.838
1375	1.875
1470	1.922
CURVE 9*	
305	0.027
580	0.652
807	0.306
1098	0.392
1138	0.143
1271	0.469
1372	0.469
1477	0.479
CURVE 10*	
303	0.019
584	0.556
805	1.262
1092	1.550
1153	1.868
1277	2.256
1388	2.465
CURVE 11*	
301	0.023
805	1.497
1092	1.580
1149	1.933
1394	2.338
1480	2.213

* No figure given.

SPECIFICATION TABLE 155. THERMAL LINEAR EXPANSION OF CHROMIUM TUNGSTEN OXIDE $Cr_2O_3 \cdot WO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	883	Martinek, C. and Hummel, F.A.	1968	L	301-1248		Bar specimen 1 x 1 x 10 cm; pressed at 1000 psi to size, and fired on platinum foil.

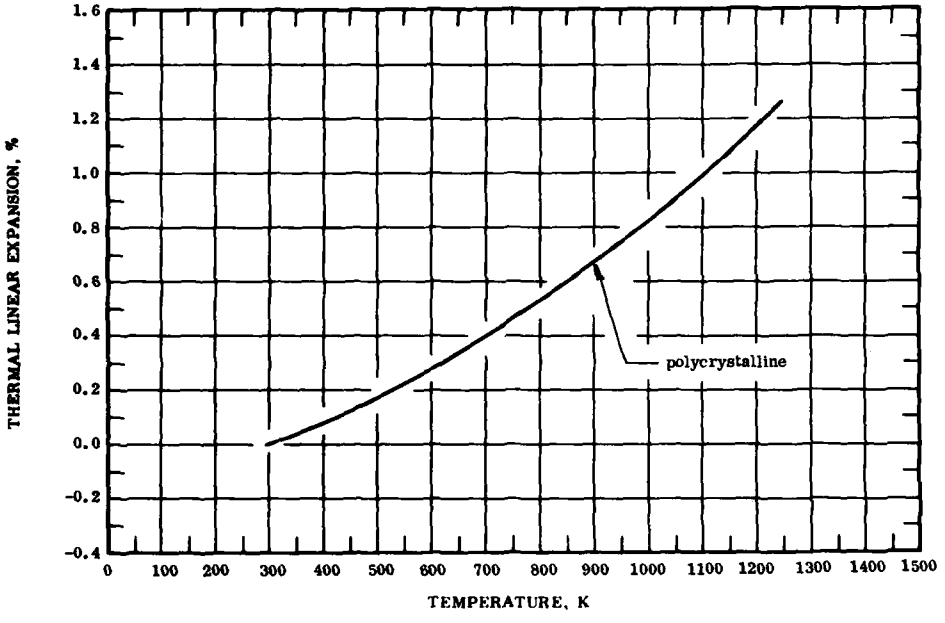
DATA TABLE 155. THERMAL LINEAR EXPANSION OF CHROMIUM TUNGSTEN OXIDE $Cr_2O_3 \cdot WO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 1 (cont.)*	
301	0.017	873	0.337
322	0.017	923	0.367
373	0.047	972	0.397
421	0.067	1022	0.427
475	0.087	1073	0.467
524	0.117	1123	0.497
572	0.137	1173	0.537
623	0.177	1223	0.567
673	0.207	1248	0.587
723	0.237		
773	0.267		
823	0.297		

* No figure given.

FIGURE AND TABLE NO. 156R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF LEAD TUNGSTEN OXIDE $PbO \cdot WO_3$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	7.1
400	0.084	8.5
500	0.175	9.7
600	0.278	11.0
700	0.400	12.2
800	0.523	13.5
900	0.664	14.7
1000	0.818	16.0
1100	0.985	17.3
1200	1.163	18.5
1250	1.257	19.2

REMARKS

The recommended values are considered accurate to within ±5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.156 + 3.505 \times 10^{-4}\, T + 6.207 \times 10^{-7}\, T^2 + 2.778 \times 10^{-12}\, T^3$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ±7%.

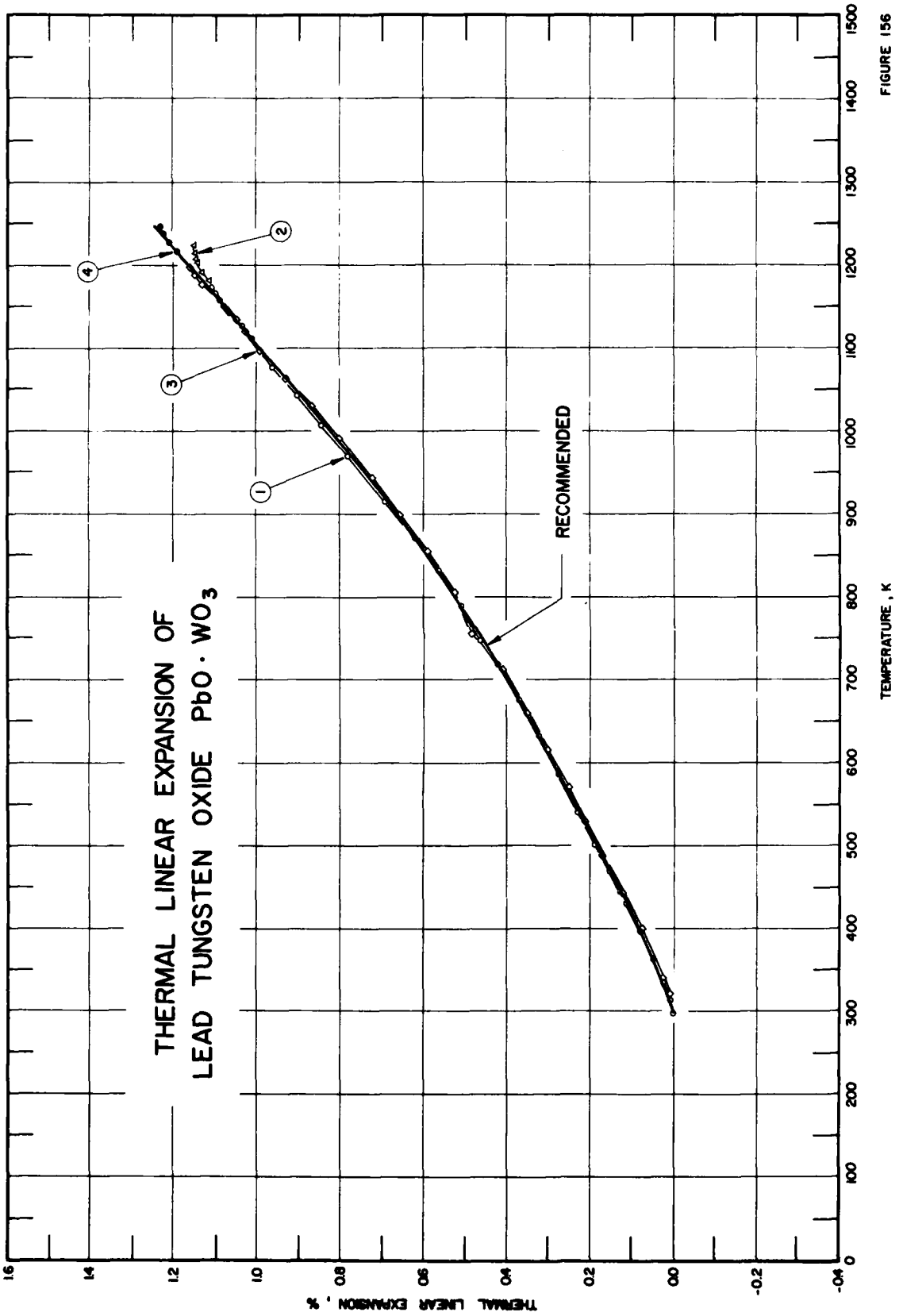

THERMAL LINEAR EXPANSION OF
LEAD TUNGSTEN OXIDE PbO · WO3
RECOMMENDED
1
2
3
4
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 156

SPECIFICATION TABLE 156. THERMAL LINEAR EXPANSION OF LEAD TUNGSTEN OXIDE $PbO \cdot WO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	286	Argyle, J. F. and Hummel, F. A.	1963	L	298-1174		49.05 PbO and 50.95 WO_3 (calculated composition); specimen prepared from C.P. chemicals hand mixed with acetone for 15 to 20 min, air dried, heated slowly to 573 K for 4 hr, remixed, calcined at 1123 K for 24 hr, cooled, remixed recalcined at 1273 K for 24 hr, ground, mixed with carbowax solution, nodulized through a 20-mesh sieve, pressed into 10 by 1 by 1 cm bars at 1000 psi, and fired slowly to 1273 K for 6 hr; original length 99 mm; measured with heating rate of 120 C per hr.
2	286	Argyle, J. F. and Hummel, F. A.	1963	L	1181-1225		Similar to the above specimen.
3	286	Argyle, J. F. and Hummel, F. A.	1963	L	298-1209		Second run of the above specimen.
4	286	Argyle, J. F. and Hummel, F. A.	1963	L	293-1249		Similar to the above specimen.
5	926	Deshpande, V. T. and Suryanarayana, S. V.	1971	X	301-628		Single crystal crushed to fine powder form, heated at 650 C for 12 hr and cooled to room temperature about 20 hr; annealed powder used to fill specimen cup of back reflection focusing camera; lattice parameter measured along a-axis; 5.4628 Å reported at 301 K.
6	926	Deshpande, V. T. and Suryanarayana, S. V.	1971	X	301-628		The above specimen; lattice parameter measured along c-axis; 12.0484 Å reported at 301 K.

DATA TABLE 156. THERMAL LINEAR EXPANSION OF LEAD TUNGSTEN OXIDE $PbO \cdot WO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 2 (cont.)		CURVE 3 (cont.)		CURVE 3 (cont.)		CURVE 5 (cont.)	
298	0.002	915	0.693	1204	1.142	661	0.354	1199	1.160	483	0.156
314	0.010	970	0.783	1209	1.144	713	0.411	1209	1.176	538	0.194
333	0.028	1008	0.847	1215	1.147	756	0.488			583	0.242
363	0.051	1043	0.906	1225	1.152	807	0.526	CURVE 4		628	0.280
397	0.082	1078	0.962			857	0.590				
431	0.115	1112	1.011	CURVE 3		900	0.657	293	0.000*	CURVE 6	
470	0.154	1127	1.039			945	0.726	1219	1.191		
501	0.190	1142	1.065	298	0.003*	991	0.801	1229	1.209	301	0.011*
541	0.231	1151	1.080	321	0.013	1031	0.870	1239	1.224	343	0.103
587	0.277	1159	1.090	340	0.029	1064	0.931	1249	1.232	378	0.180
632	0.326	1167	1.101	363	0.049*	1097	0.991			438	0.293
676	0.372	1174	1.111	400	0.080	1121	1.029	CURVE 5		483	0.393
719	0.421			444	0.121	1135	1.052			538	0.511
747	0.467	CURVE 2		489	0.172	1147	1.075	301	0.002	583	0.611
791	0.511			531	0.216	1159	1.096*	343	0.046	628	0.720
833	0.564	1181	1.119	572	0.257	1177	1.132	378	0.077		
871	0.621	1191	1.131	617	0.306	1189	1.150	438	0.121		

* Not shown in figure.

SPECIFICATION TABLE 157. THERMAL LINEAR EXPANSION OF LEAD IRON TUNGSTEN OXIDE $3PbO \cdot Fe_2O_3 \cdot WO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	286	Argyle, J. F. and Hummel, F. A.	1963	L	298-970		63.10 PbO, 15.05 Fe_2O_3, and 21.85 WO_3 (calculated composition); specimen prepared from C.P. chemicals hand mixed with acetone for 15 to 20 min, air dried, heated slowly to 573 K for 4 hr, remixed, calcined at 873 K for 24 hr, cooled, remixed, recalcined at 973 K for 24 hr, ground, mixed with carbowax solution, nodulized through a 20-mesh sieve, pressed into 10 by 1 by 1 cm bars at 1000 psi, and fired slowly to 973 K for 6 hr; original length 88.3 mm; measured with heating rate of 120 C per hr.
2*	286	Argyle, J. F. and Hummel, F. A.	1963	L	298-970		Second run of the above specimen.

DATA TABLE 157. THERMAL LINEAR EXPANSION OF LEAD IRON TUNGSTEN OXIDE $3PbO \cdot Fe_2O_3 \cdot WO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
298	0.001
330	0.015
357	0.038
385	0.068
415	0.095
443	0.127
473	0.165
507	0.202
540	0.242
562	0.291
621	0.349
661	0.403
707	0.463
744	0.518
791	0.584
CURVE 1 (cont.)*	
843	0.659
887	0.723
934	0.792
958	0.823
970	0.835
CURVE 2*	
298	0.001
325	0.013
356	0.038
381	0.064
407	0.090
437	0.122
465	0.153
497	0.191
538	0.237
581	0.291
621	0.346
666	0.404
711	0.464
758	0.539
805	0.605
831	0.648
861	0.686
899	0.740
953	0.821
970	0.835
CURVE 2 (cont.)*	

* No figure given.

SPECIFICATION TABLE 158. THERMAL LINEAR EXPANSION OF MAGNESIUM LEAD TUNGSTEN OXIDE $MgO \cdot 2PbO \cdot WO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	286	Argyle, J. F. and Hummel, F. A.	1963	L	293-1103		62.12 PbO, 32.27 WO_3, and 5.61 MgO (calculated composition); specimen prepared from C. P. chemicals hand mixed with acetone for 15 to 20 min, air dried, heated slowly to 573 K for 4 hr, remixed, calcined at 1073 K for 24 hr, cooled, remixed, recalcined at 1173 K for 24 hr, ground, mixed with carbowax solution, nodulized through a 20-mesh sieve, pressed into 10 by 1 by 1 cm bars at 1000 psi, and fired slowly to 1173 K for 6 hr; original length 97 mm; measured with heating rate of 120 C per hr.
2*	286	Argyle, J. F. and Hummel, F. A.	1963	L	298-1061		Second run of the above specimen.

DATA TABLE 158. THERMAL LINEAR EXPANSION OF MAGNESIUM LEAD TUNGSTEN OXIDE $MgO \cdot 2PbO \cdot WO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 1 (cont.)*		CURVE 2*		CURVE 2 (cont.)*	
298	-0.002	537	0.079	298	-0.001	465	0.002
311	-0.012	572	0.124	306	-0.004	502	0.044
313	-0.023	605	0.163	308	-0.006	535	0.083
315	-0.044	640	0.208	311	-0.014	568	0.122
317	-0.067	673	0.247	313	-0.035	603	0.164
317	-0.086	709	0.289	315	-0.051	637	0.206
318	-0.107	747	0.336	317	-0.066	678	0.256
320	-0.125	791	0.383	319	-0.085	719	0.305
323	-0.128	829	0.417	321	-0.108	756	0.353
337	-0.125	873	0.469	323	-0.124	794	0.400
340	-0.120	917	0.524	325	-0.127	832	0.449
358	-0.107	960	0.577	331	-0.127	869	0.499
395	-0.075	1009	0.621	334	-0.124	912	0.554
427	-0.044	1051	0.629	342	-0.122	949	0.599
461	-0.007	1089	0.627	385	-0.059	987	0.643
499	0.035	1103	0.616	429	-0.040	1027	0.677
						1061	0.688

* No figure given.

SPECIFICATION TABLE 159. THERMAL LINEAR EXPANSION OF SODIUM TUNGSTEN OXIDE $Na_2O \cdot WO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	927	Austin, J.B. and Pierce, R.H.H.	1935	I	286-863		Good commercial grade recrystallized from water, fused into gold, and cut to size; expansion measured on first run under load of 63 grams.
2*	927	Austin, J.B. and Pierce, R.H.H.	1935	I	286-863		The above specimen; expansion on second test.
3*	927	Austin, J.B. and Pierce, R.H.H.	1935	I	321-866		The above specimen; expansion on third test.

* No figure given.

DATA TABLE 159. THERMAL LINEAR EXPANSION OF SODIUM TUNGSTEN OXIDE $Na_2O \cdot WO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
286	-0.015
304	0.023
319	0.039
340	0.089
350	0.094
376	0.145
386	0.183
398	0.197
415	0.246
422	0.250
430	0.278
444	0.302
457	0.340
465	0.354
470	0.372
482	0.402
497	0.434
506	0.453
524	0.495
538	0.527
547	0.548
564	0.588
571	0.609
576	0.618
590	0.649
603	0.678
616	0.710
629	0.742
635	0.762
642	0.774
654	0.803
664	0.834
669	0.861
678	0.870
691	0.897
693	0.915
703	0.926
715	0.958
726	0.991
732	1.014
745	1.039
762	1.064
771	1.064
779	1.055
783	1.042
790	1.015

T	$\Delta L/L_0$
CURVE 1 (cont.)*	
805	0.966
808	0.914
812	0.864
819	0.769
826	0.663
831	0.564
838	0.465
847	0.364
855	0.261
861	0.360
862	0.728
863	1.014
863	1.121
CURVE 2*	
286	-0.015
304	0.023
319	0.039
340	0.089
350	0.094
376	0.145
386	0.183
398	0.197
415	0.246
422	0.250
430	0.278
444	0.302
457	0.340
465	0.354
470	0.372
482	0.402
497	0.434
506	0.453
524	0.495
538	0.527
547	0.548
564	0.588
571	0.609
576	0.618
590	0.649
603	0.678
616	0.710
629	0.742
635	0.762
642	0.774

T	$\Delta L/L_0$
CURVE 2 (cont.)*	
654	0.803
664	0.834
669	0.861
678	0.870
691	0.897
693	0.915
703	0.926
715	0.958
726	0.991
732	1.014
745	1.039
775	1.118
789	1.127
797	1.120
805	1.102
814	1.079
817	1.059
823	1.018
829	0.968
841	0.918
851	0.868
859	0.915
863	1.014
863	1.121
CURVE 3*	
321	0.054
371	0.151
400	0.216
415	0.247
442	0.312
485	0.410
526	0.496
592	0.662
607	0.693
652	0.814
668	0.860
716	0.957
719	0.972
750	1.053
761	1.082
781	1.135
787	1.146
793	1.160
797	1.145

T	$\Delta L/L_0$
CURVE 3 (cont.)*	
805	1.183
814	1.196
820	1.210
827	1.221
832	1.233
838	1.245
846	1.251
853	1.260
861	1.268
864	1.279
865	1.349
865	1.420
866	1.529
866	1.585

* No figure given.

SPECIFICATION TABLE 160. THERMAL LINEAR EXPANSION OF ZIRCONIUM TUNGSTEN OXIDE $ZrO_2 \cdot 2WO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	883	Martinek, C. and Hummel, F.A.	1968	L	301-978	ZrW_2O_8	Bar specimen 1 x 1 x 10 cm, pressed at 1000 psi to size, and fired on platinum foil.

DATA TABLE 160. THERMAL LINEAR EXPANSION OF ZIRCONIUM TUNGSTEN OXIDE $ZrO_2 \cdot 2WO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 1 (cont.)*	
301	-0.00	698	-0.24
323	-0.00	738	-0.25
349	-0.01	773	-0.26
368	-0.03	823	-0.27
393	-0.05	848	-0.28
414	-0.07	873	-0.29
433	-0.10	913	-0.30
453	-0.13	943	-0.32
475	-0.15	978	-0.33
498	-0.16		
548	-0.17		
588	-0.19		
623	-0.21		
663	-0.22		

* No figure given.

SPECIFICATION TABLE 161. THERMAL LINEAR EXPANSION OF CHROMIUM VANADIUM OXIDE $Cr_2O_3 \cdot V_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	986	Riedner, R.J. and Cartz, L.	1971	X	298, 973		Orthorhombic crystal structure specimen; both photographic and diffractonate methods used; sample heated by radiation from wire-wound furnace; expansion measured along a-axis.
2*	986	Riedner, R.J. and Cartz, L.	1971	X	298, 973		The above specimen; expansion measured along b-axis.
3*	986	Riedner, R.J. and Cartz, L.	1971	X	298, 973		The above specimen; expansion measured along c-axis.

DATA TABLE 161. THERMAL LINEAR EXPANSION OF CHROMIUM VANADIUM OXIDE $Cr_2O_3 \cdot V_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
298	0.003
973	0.394
CURVE 2*	
298	0.003
973	0.462
CURVE 3*	
298	0.004
973	0.530

* No figure given.

SPECIFICATION TABLE 162. THERMAL LINEAR EXPANSION OF NIOBIUM VANADIUM OXIDE $Nb_2O_5 \cdot V_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	333	Brown, J.J., Jr.	1964	L	293-1056	NV	Bar specimen, approximately 10 x 1 x 1 cm; Nb_2O_5 and V_2O_5 mixed by molar ratio 1:1; heated at 125 C per hr in Nichrome-Wound Vertical tube furnace; data from smoothed curve.

DATA TABLE 162. THERMAL LINEAR EXPANSION OF NIOBIUM VANADIUM OXIDE $Nb_2O_5 \cdot V_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
373	0.012
473	0.021
573	0.027
673	0.034
773	0.047
823	0.058
873	0.078
923	0.109
973	0.129
1013	0.129
1056	0.121

* No figure given.

SPECIFICATION TABLE 163. THERMAL LINEAR EXPANSION OF TANTALUM VANADIUM OXIDE $Ta_2O_5 \cdot V_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	333	Brown, J.J., Jr.	1964	L	293-973	αTV	Bar specimen, approximately 10 x 1 x 1 cm; Ta_2O_5 and V_2O_5 mixed by molar ratio 1:1; heated at 125 C per hr in Nichrome-Wound vertical tube furnace; data from smoothed curve.
2*	333	Brown, J.J., Jr.	1964	L	293-1093	βTV	Similar to the above specimen except of different phase.

DATA TABLE 163. THERMAL LINEAR EXPANSION OF TANTALUM VANADIUM OXIDE $Ta_2O_5 \cdot V_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*	
293	0.000	293	0.000
373	-0.033	373	-0.008
473	-0.075	473	-0.018
573	-0.112	573	-0.027
673	-0.150	673	-0.036
773	-0.187	773	-0.047
873	-0.222	873	-0.057
973	-0.260	957	-0.066
		973	-0.064
		1023	-0.045
		1073	0.000
		1093	0.020

* No figure given.

SPECIFICATION TABLE 164. THERMAL LINEAR EXPANSION OF ZINC VANADIUM OXIDE $ZnO \cdot V_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	725	Brown, J.J. and Hummel, F.A.	1965	L	287-791		1 x 1 x 10 cm bar specimen; batches of C.P. grade mixed, air-dried, heated slowly in a Globar furnace to 873 K; remixed, and allowed to equilibrate at 873 K in 48 hr before being ground, mixed with a Carbowax solution and pressed into bar at 1000 psi bar fired to 888 K; aggregate thermal expansion measured heating rate 120 C per hr.
2*	333	Brown, J.J., Jr.	1964	L	284-860		Bar specimen, approximately 10 x 1 x 1 cm; heated at 125 C per hr in Nichrome-Wound vertical tube furnace; data from smoothed curve; zero-point correction -0.011%.

DATA TABLE 164. THERMAL LINEAR EXPANSION OF ZINC VANADIUM OXIDE $ZnO \cdot V_2O_5$

[*Temperature*, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*	
287	-0.002	284	-0.011
293	0.000	293	0.000
323	0.004	373	0.064
373	0.018	473	0.143
423	0.038	573	0.221
473	0.059	673	0.302
523	0.089	773	0.381
573	0.116	807	0.406
623	0.154	831	0.414
673	0.193	860	0.417
723	0.247		
773	0.311		
791	0.354		

* No figure given.

SPECIFICATION TABLE 165. THERMAL LINEAR EXPANSION OF ZINC VANADIUM OXIDE $2ZnO \cdot V_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	725	Brown, J.J. and Hummel, F.A.	1965	L	287-804	α-$Zn_2V_2O_7$	Phase α-$Zn_2V_2O_7$; 1 x 1 x 10 cm bar; batches of C.P. grade mixed, air-dried, heated slowly in a Globar furnace to 600 C; remixed, allowed to react and equilibrate at 600 C in 48 hr before being ground, mixed with a Carbowas solution, pressed into bar at 1000 psi; bar fired to 615 C; aggregate thermal expansion measured, heating rate 120 C/hr.
2*	333	Brown, J.J., Jr.	1964	L	281-786	α-$Zn_2V_2O_7$	Bar specimen, approximately 10 x 1 x 1 cm; heated at 125 C per hr in Nichrome-Wound vertical tube furnace; data from smoothed curve.

DATA TABLE 165. THERMAL LINEAR EXPANSION OF ZINC VANADIUM OXIDE $2ZnO \cdot V_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*	
287	-0.005	281	-0.002
293	0.000	293	0.000
323	0.002	373	0.004
373	0.004	473	-0.004
423	0.004	573	-0.021
473	0.000	673	-0.047
523	-0.007	773	-0.077
573	-0.018	786	-0.081
623	-0.030		
673	-0.045		
723	-0.070		
773	-0.087		
804	-0.106		

* No figure given.

SPECIFICATION TABLE 166. THERMAL LINEAR EXPANSION OF ZINC VANADIUM OXIDE $3ZnO \cdot V_2O_5$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	725	Brown, J.J. and Hummel, F.A.	1965	L	287-995	α-$Zn_3(VO_4)_2$	Phase α-$Zn_3(VO_4)_2$; 1 x 1 x 10 cm bar; batches of C.P. grade, mixed, air-dried, heated slowly in a Globar furnace to 600 C, remixed, allowed to react and to equilibrate at 700 C before being ground, mixed with a Carbowax solution and pressed into bar at 1000 psi, bar fired to 775 C; heating rate 120 C per hr for thermal expansion measurements.
2*	725	Brown, J.J. and Hummel, F.A.	1965	L	287-1118	β-$Zn_3(VO_4)_2$	Phase β-$Zn_3(VO_4)_2$; similar to the above specimen; bar fired to 810 C.
3*	333	Brown, J.J., Jr.	1964	L	281-973	α-$Zn_3(VO_4)_2$	Bar specimen, approximately 10 x 1 x 1 cm; heated at 125 C per hr in Nichrome-Wound vertical tube furnace; data from smoothed curve.
4*	333	Brown, J.J., Jr.	1964	L	281-1015	β-$Zn_3(VO_4)_2$	Similar to the above specimen; it was impossible to get pure β-$Zn_3(VO_4)_2$, specimen contained substantial amount (5 to 20 mole %) α-$Zn_3(VO_4)_2$; data from smoothed curve.

DATA TABLE 166. THERMAL LINEAR EXPANSION OF ZINC VANADIUM OXIDE $3ZnO \cdot V_2O_5$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*		CURVE 2 (cont.)*		CURVE 4*	
287	-0.006	287	-0.004	1073	0.639	281	-0.004
293	0.000	293	0.000	1097	0.640	293	0.000
323	0.019	323	0.008	1118	0.632	373	0.037
373	0.047	373	0.033			473	0.092
423	0.084	423	0.059	CURVE 3*		573	0.161
473	0.123	473	0.086			673	0.252
523	0.174	523	0.123	281	-0.012	773	0.352
573	0.222	573	0.160	293	0.000	873	0.448
623	0.277	623	0.212	373	0.076	973	0.548
673	0.335	673	0.265	473	0.170	1015	0.585
723	0.398	723	0.332	573	0.266		
773	0.463	773	0.390	673	0.359		
823	0.523	823	0.447	773	0.454		
873	0.568	873	0.501	838	0.514		
923	0.605	923	0.553	873	0.538		
973	0.625	973	0.593	923	0.557		
995	0.628	1023	0.625	973	0.563		

* No figure given.

SPECIFICATION TABLE 167. THERMAL LINEAR EXPANSION OF BARIUM ZIRCONIUM OXIDE $BaO \cdot ZrO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	928	Branson, D.L.	1965	I	296-973		Specimen prepared by pressing -325 mesh powders into cylindrical shape, sintering and grinding, and shaping into pyramid ~0.25 in. high; bulk density 6.73 g cm^{-3}.
2*	929	Wheildon, W.M.	1967	L	293-1373		Specimen 1/8 x 1/8 x 2 in. section cut from very thick coating and diamond ground all over to dimensions; crystal cubic form, bulk density 5.25 g cm^{-3}, porosity (total) 10.0%.

DATA TABLE 167. THERMAL LINEAR EXPANSION OF BARIUM ZIRCONIUM OXIDE $BaO \cdot ZrO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2 (cont.)*	
296	0.002	773	0.346
487	0.108	823	0.382
597	0.180	873	0.418
973	0.446	923	0.452
		973	0.484
CURVE 2*		1023	0.514
		1073	0.544
293	0.000	1123	0.570
323	0.020	1148	0.584
373	0.046	1173	0.592
423	0.078	1198	0.592
473	0.116	1223	0.588
523	0.150	1273	0.608
573	0.190	1323	0.642
623	0.228	1373	0.680
673	0.266		
723	0.306		

* No figure given.

SPECIFICATION TABLE 168. THERMAL LINEAR EXPANSION OF CADMIUM ZIRCONIUM OXIDE $CdO \cdot ZrO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	928	Branson, D. L.	1965	I	296-973		Specimen prepared by pressing -325 mesh powders into cylindrical shape, sintering and grinding, and shaping into pyramid ~0.25 in. high; bulk density 6.38 g cm^{-3}.

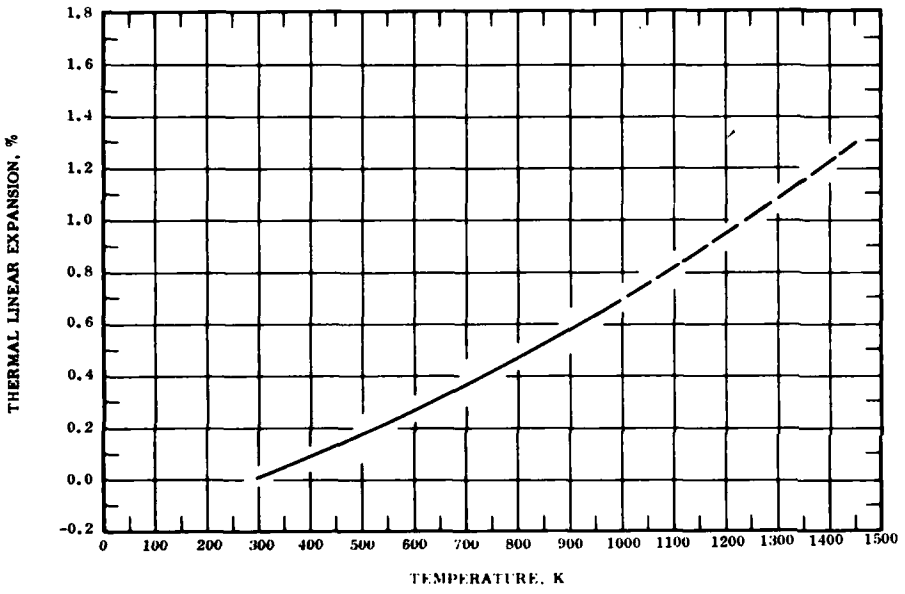
DATA TABLE 168. THERMAL LINEAR EXPANSION OF CADMIUM ZIRCONIUM OXIDE $CdO \cdot ZrO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
296	0.003
426	0.120
575	0.277
973	0.739

* No figure given.

FIGURE AND TABLE NO. 169R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF CALCIUM ZIRCONIUM OXIDE $CaO \cdot ZrO_2$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, $10^{-6}\ K^{-1}$]

T	$\Delta L/L_0$	α
293	0.000	7.9
400	0.087	8.4
500	0.174	8.9
600	0.266	9.5
700	0.364	10.0
800	0.467	10.6
900	0.577	11.2
1000	0.692	11.9
1100	0.814†	12.5
1200	0.945†	13.2
1300	1.079†	13.9
1400	1.222†	14.7
1450	1.296†	15.0

† Provisional values.

REMARKS

The recommended values are based on the data for pure sample (curves 1 and 2) and are considered accurate to within ±3% at temperatures below 1000 K and ±10% above 1000 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.213 + 6.633 \times 10^{-4}\ T + 1.999 \times 10^{-7}\ T^2 + 4.145 \times 10^{-11}\ T^3$$

The tabulated values for the coefficient of thermal expansion are primarily calculated by differentiating of the above equation and are considered accurate to about ±10%.

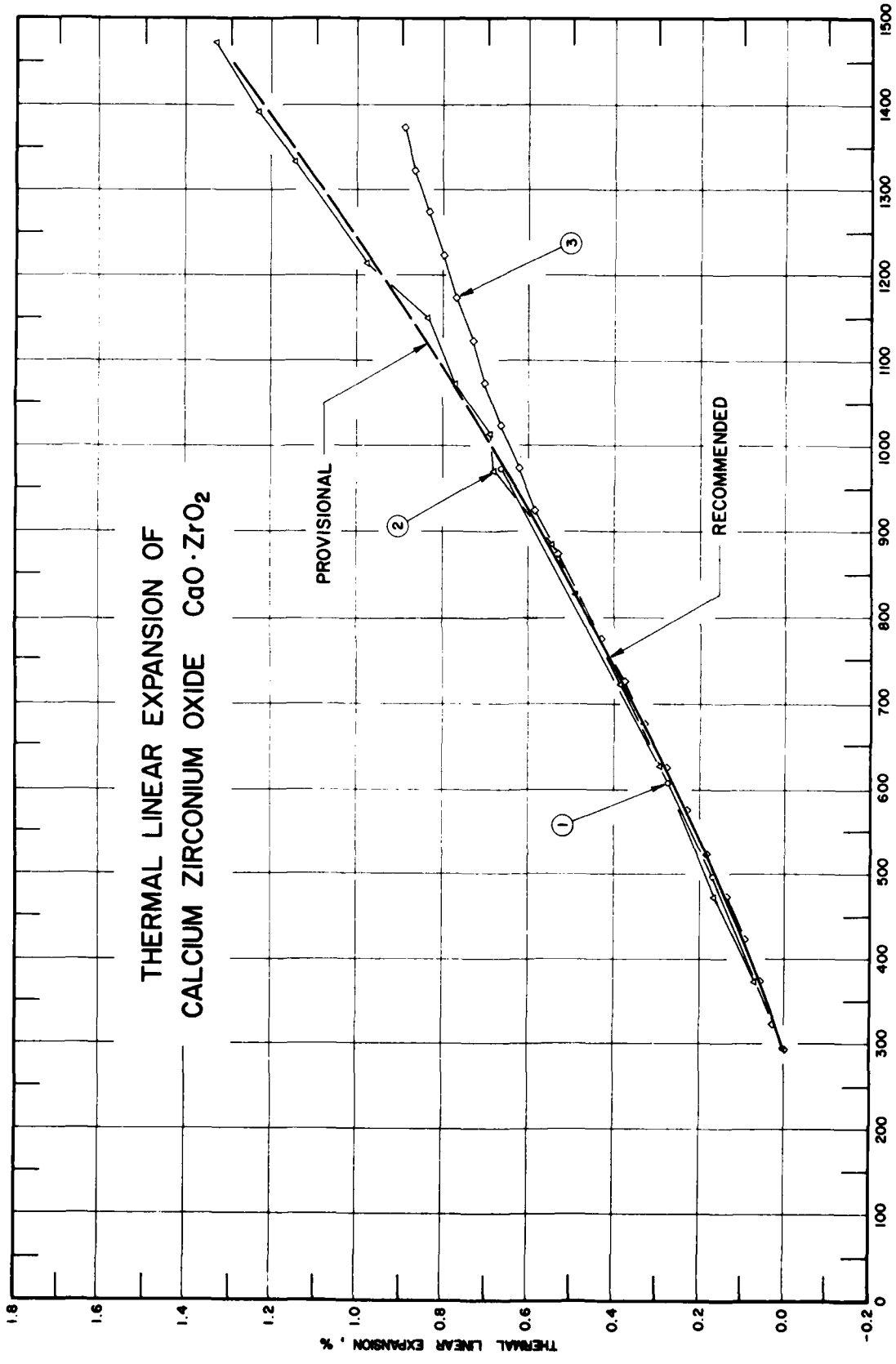

THERMAL LINEAR EXPANSION OF
CALCIUM ZIRCONIUM OXIDE CaO·ZrO2
PROVISIONAL
RECOMMENDED
1
2
3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 169

SPECIFICATION TABLE 169. THERMAL LINEAR EXPANSION OF CALCIUM ZIRCONIUM OXIDE $CaO \cdot ZrO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	*Composition (weight percent), Specifications, and Remarks*
1	928	Branson, D. L.	1965	I	296-973	$CaZrO_3$	Specimen prepared by pressing -325 mesh powders into cylindrical shape, sintering and grinding, and shaping into pyramids ~ 0.25 in. high; bulk density 4.95 g cm^{-3}.
2	930	Nadler, M. R. and Fitzsimmons, E. S.	1955	T	373-1473		99.0 pure, formed from equimolar proportions of $CaCO_3$ and ZrO_2 subjected to a final temperature of 1850 C; test bar heated in a Globar resistance furnace.
3	929	Wheildon, W. M.	1967	L	293-1373		Specimen 1/8 x 1/8 x 2 in. section cut from very thick coating and diamond ground all over to dimensions, crystal form: cubic; bulk density: 4.14; porosity (total) 5.7%.

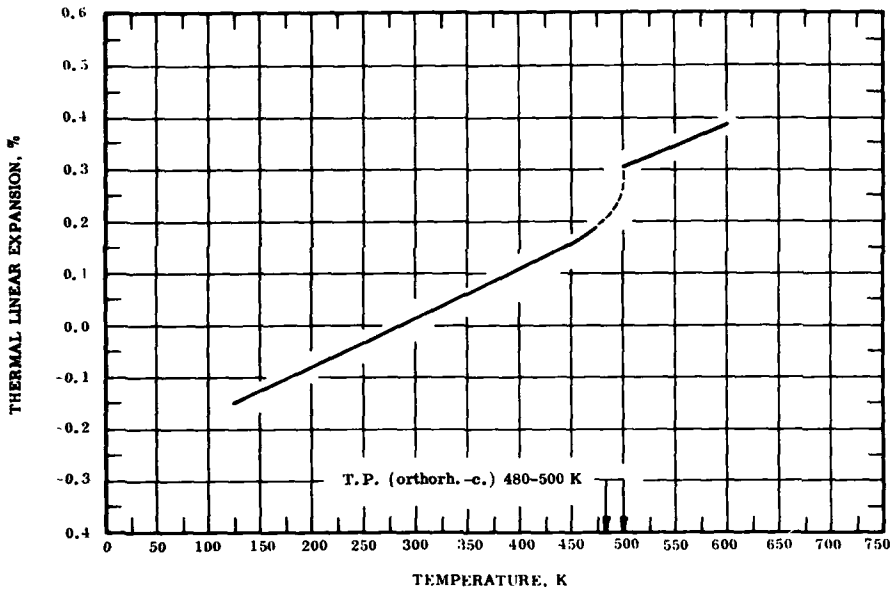
DATA TABLE 169. THERMAL LINEAR EXPANSION OF CALCIUM ZIRCONIUM OXIDE $CaO \cdot ZrO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
296	0.002
496	0.171
606	0.276
973	0.665
CURVE 2	
373	0.072
473	0.165
625	0.295
720	0.385
827	0.491
884	0.545
970	0.681
1014	0.696
1072	0.773
CURVE 2 (cont.)	
1150	0.838
1215	0.980
1333	1.145
1391	1.236
1473	1.332
CURVE 3	
293	0.000
323	0.023
373	0.059
423	0.093
473	0.138
523	0.183
573	0.231
623	0.278
CURVE 3 (cont.)	
673	0.328
723	0.377
773	0.433
823	0.487*
873	0.532
923	0.582
973	0.621
1023	0.666
1073	0.705
1123	0.730
1173	0.769
1223	0.800
1273	0.835
1323	0.868
1373	0.893

* Not shown in figure.

FIGURE AND TABLE NO. 170R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF LEAD ZIRCONIUM OXIDE $PbO \cdot ZrO_2$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
125	-0.145	8.2
150	-0.125	8.3
175	-0.104	8.4
200	-0.083	8.5
225	-0.061	8.7
250	-0.039	8.8
275	-0.017	9.0
293	0.000	9.2
325	0.029	9.4
350	0.053	9.7
375	0.078	9.9
400	0.103	10.2
425	0.128	10.4
450	0.155	10.7
475	0.182	11.0
500†	0.310	7.5
525	0.328	7.5
550	0.347	7.5
575	0.367	7.6
600	0.385	7.7

† Transition temperature.

REMARKS

The recommended values are based on the data for the most pure samples (curves 5, 7 and 8). The variation of the transition temperature depends upon the heating/cooling rate. These values are considered accurate to within ±5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.246 + 7.921 \times 10^{-4}\, T + 3.238 \times 10^{-6}\, T^2 + 4.112 \times 10^{-10}\, T^3 \quad (125\text{-}475\ K)$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ±7%.

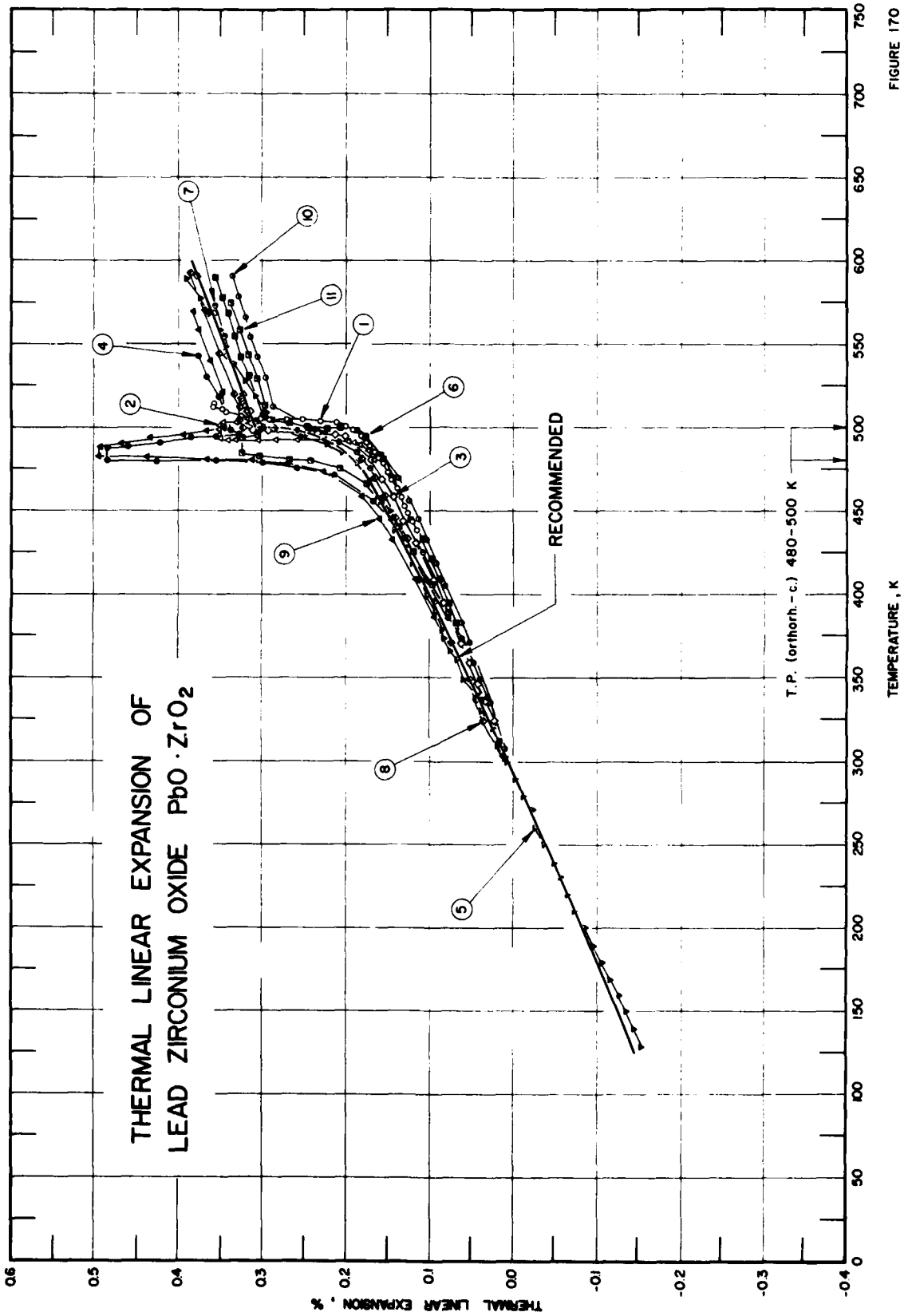

THERMAL LINEAR EXPANSION OF
LEAD ZIRCONIUM OXIDE PbO · ZrO2
RECOMMENDED
T.P. (orthorh.-c.) 480-500 K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
1
2
3
4
5
6
7
8
9
10
11

FIGURE 170

SPECIFICATION TABLE 170. THERMAL LINEAR EXPANSION OF LEAD ZIRCONIUM OXIDE $PbO \cdot ZrO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	931	Goulpean, L.	1967	X	438-515		Impurity not exceed 10^{-2} percent is ZrO_2 or 10^{-4} percent in the PbO; final ignition of the ceramic carried out is an atmosphere of PbO vapor at 1600 C; transition temperature 232 and 235 C on heating, and 219 and 230 C on cooling.
2	931	Goulpean, L.	1967	X	518-481		The above specimen, expansion measured with decreasing temperature.
3	932	Tennery, V.J.	1966	X	324-592		Sintered discs of material manually crushed and -325 mesh fraction separated; specimen annealed at 550 C for 3 hr.
4	932	Tennery, V.J.	1966	X	324-568		The above specimen except expansion measured with decreasing temperature.
5	933	Shirani, G., Sawagrichi, E., and Takeda, A.	1950	L	128-590	Ceramic lead Zirconate	Prepared by sintering a mixture of pure ZrO_2 and PbO at 1100 C; specimen 3 cm in length; measured by dilatometer consisting of silica rods and optical lead.
6	934	Tennery, V.J.	1966	L	302-591	A	Raw materials ultra high purity PbO from Hammond Lead Products, Inc. and C.P. ZrO_2 from Titanium Zirconium Co.; dry powders mixed 20 min methanol added, blended 30 min; alcohol evaporated, broken to -100 mesh; calcined 2 hr at 1073 K in platinum crucible; passed through 100 mesh screen, sintered to high density 1 hr at 1513 K; only $PbZrO_3$ observed in x-ray analysis.
7	934	Tennery, V.J.	1966	L	591-395	A	The above specimen, expansion measured with decreasing temperature.
8	934	Tennery, V.J.	1966	L	303-597	B	Second specimen similar to the above specimen; expansion measured with increasing temperature.
9	934	Tennery, V.J.	1966	L	593-372	B	The above specimen, expansion measured with decreasing temperature.
10	934	Tennery, V.J.	1966	L	307-592	D	Similar to the above specimen except zirconia containing 50 ppm hafnium from National Lead Co. used as starting material; expansion measured with increasing temperature.
11	934	Tennery, V.J.	1966	L	592-335	D	The above specimen; expansion measured with decreasing temperature.
12*	934	Tennery, V.J.	1966	L	307-589	$Pb_{0.999}Ca_{0.001}ZrO_3$	Similar to specimen A for curve numbers 6 and 7, except 0.03% calcium substituted for lead; expansion measured with increasing temperature.
13*	934	Tennery, V.J.	1966	L	589-470	$Pb_{0.999}Ca_{0.001}ZrO_3$	The above specimen; expansion measured with decreasing temperature.
14*	934	Tennery, V.J.	1966	L	311-586	$Pb_{0.995}Ca_{0.005}ZrO_3$	Similar to the above specimen except 0.1% calcium; expansion measured with increasing temperature.
15*	934	Tennery, V.J.	1966	L	586-382	$Pb_{0.995}Ca_{0.005}ZrO_3$	The above specimen; expansion measured with decreasing temperature.

* Not shown in figure.

DATA TABLE 170. THERMAL LINEAR EXPANSION OF LEAD ZIRCONIUM OXIDE $PbO \cdot ZrO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
438	0.114
443	0.120
448	0.125
453	0.130
458	0.134
463	0.139
468	0.146
473	0.151
478	0.156
482	0.161
486	0.165
489	0.171
492	0.176
495	0.181
499	0.192
501	0.200
503	0.210
504	0.230
505	0.251
505	0.270
505	0.290
506	0.301
506	0.313
507	0.323
509	0.322
511	0.324
513	0.326
515	0.329
CURVE 2	
518	0.326
516	0.324
515	0.322
513	0.321
510	0.319
508	0.316
505	0.315
503	0.315
503	0.330
503	0.346
502	0.351
498	0.351
496	0.351
494	0.350
493	0.341

T	$\Delta L/L_0$
CURVE 2 (cont.)	
493	0.331
493	0.305
493	0.282
493	0.258
493	0.222
492	0.197
491	0.190
490	0.182
487	0.172
484	0.166
481	0.164
CURVE 3	
324	0.022
336	0.032
347	0.043
358	0.052
371	0.063
396	0.083
408	0.095
432	0.118
444	0.131
459	0.144
469	0.158
481	0.169
494	0.200
496	0.212
497	0.234
497	0.249
498	0.291
499	0.312
499	0.337
503	0.316*
510	0.316
520	0.321
543	0.341
568	0.359
592	0.378
CURVE 4	
568	0.373
556	0.366
538	0.352
499	0.339

T	$\Delta L/L_0$
CURVE 4 (cont.)	
497	0.327
495	0.357
494	0.384
492	0.422
489	0.460
488	0.483
481	0.483
480	0.426
480	0.355
479	0.299
476	0.259
472	0.213
456	0.167
445	0.147
433	0.131
408	0.104
487	0.078
373	0.061
359	0.050
348	0.040
337	0.030
324	0.020*
CURVE 5	
128	-0.153
139	-0.146
150	-0.136
159	-0.129
168	-0.117
179	-0.107
189	-0.097
200	-0.088
210	-0.075
219	-0.068
231	-0.057
239	-0.050
250	-0.039
260	-0.029
271	-0.024
279	-0.012
289	-0.003
300	0.006
309	0.018
319	0.022
330	0.038

T	$\Delta L/L_0$
CURVE 5 (cont.)	
338	0.047
349	0.059
361	0.067
367	0.074
374	0.081
379	0.086
389	0.092
398	0.103
409	0.110
419	0.120
429	0.129
438	0.140
450	0.148
459	0.161
468	0.170
479	0.286
486	0.203
491	0.221
495	0.254
500	0.282
510	0.293
519	0.307
529	0.320
539	0.332
549	0.342
558	0.350
568	0.362
578	0.372
590	0.390
CURVE 6	
302	0.008
311	0.016
337	0.033
359	0.051*
372	0.060*
383	0.069
395	0.078
409	0.088
422	0.099
433	0.109
445	0.121
458	0.434*
470	0.146
483	0.159

T	$\Delta L/L_0$
CURVE 6 (cont.)	
495	0.177
498	0.188
500	0.206
500	0.209*
500	0.221
501	0.249
503	0.269
505	0.289
507	0.298
519	0.307*
532	0.315
543	0.324
555	0.331
568	0.340
579	0.347
591	0.356
CURVE 7	
591	0.356*
573	0.356
555	0.346
540	0.334*
521	0.321*
510	0.314*
503	0.308
498	0.285
497	0.258
496	0.233*
492	0.207
486	0.187
476	0.171
459	0.148*
442	0.130
426	0.108
395	0.078*
CURVE 8	
303	0.011
324	0.035
337	0.043
349	0.053
361	0.064*
372	0.074
396	0.094

T	$\Delta L/L_0$
CURVE 8 (cont.)	
409	0.106*
433	0.129
446	0.141
459	0.154
470	0.168
482	0.180
496	0.212*
498	0.222*
499	0.245
499	0.259*
500	0.300
500	0.322
505	0.326
513	0.326
521	0.332
545	0.351
570	0.367
593	0.384
CURVE 9	
593	0.384*
570	0.382
558	0.376
541	0.361
522	0.349
500	0.337*
500	0.348
498	0.367
496	0.393
494	0.434
491	0.469
489	0.492
483	0.493
483	0.437
482	0.365
481	0.311
478	0.270
474	0.223
459	0.180
446	0.160
433	0.146
409	0.116
387	0.091
372	0.074*

* Not shown in figure.

DATA TABLE 170. THERMAL LINEAR EXPANSION OF LEAD ZIRCONIUM OXIDE $PbO \cdot ZrO_2$ (continued)

T	$\Delta L/L_0$
CURVE 10	
307	0.010
323	0.021*
335	0.029
359	0.044*
372	0.052
383	0.062
406	0.081
419	0.091
433	0.103
445	0.112
457	0.125
470	0.138
482	0.155
494	0.185*
497	0.211*
498	0.235
499	0.260*
500	0.285*
513	0.285
531	0.295
543	0.305
555	0.313
567	0.320
579	0.327
592	0.335
CURVE 11	
592	0.335*
576	0.337
559	0.326
544	0.316
530	0.306
513	0.295
498	0.291*
496	0.304
494	0.323
485	0.323
483	0.302
481	0.268
480	0.241
476	0.206
467	0.175
456	0.158
441	0.137
426	0.118
407	0.098

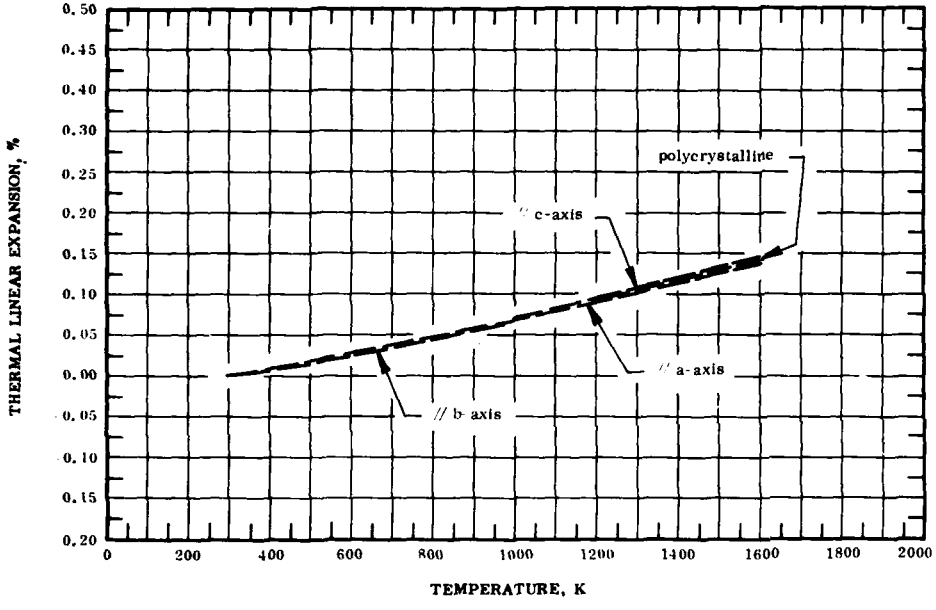
T	$\Delta L/L_0$
CURVE 11 (cont.)	
389	0.079
374	0.062*
335	0.029*
CURVE 12*	
307	0.010
323	0.022
347	0.036
358	0.044
371	0.052
383	0.062
403	0.078
419	0.094
433	0.106
445	0.118
458	0.131
470	0.142
482	0.154
494	0.174
497	0.190
499	0.196
500	0.214
501	0.240
502	0.258
505	0.268
520	0.280
532	0.288
544	0.294
556	0.302
568	0.310
580	0.318
589	0.326
CURVE 13*	
589	0.325
573	0.325
556	0.314
537	0.301
519	0.290
507	0.283
500	0.278
494	0.294
490	0.294
490	0.284
489	0.262

T	$\Delta L/L_0$
CURVE 13 (cont.)*	
488	0.220
488	0.191
484	0.173
475	0.153
470	0.142
CURVE 14*	
311	0.014
323	0.022
347	0.038
370	0.054
382	0.062
394	0.070
407	0.082
420	0.092
432	0.102
445	0.112
457	0.124
470	0.136
482	0.150
494	0.168
499	0.178
500	0.206
501	0.242
501	0.272
506	0.282
519	0.290
531	0.298
543	0.306
555	0.314
567	0.324
586	0.336
CURVE 15*	
586	0.336
566	0.338
555	0.329
543	0.321
531	0.314
518	0.305
507	0.297
502	0.294
499	0.285
498	0.270
497	0.248

T	$\Delta L/L_0$
CURVE 15 (cont.)*	
495	0.214
492	0.194
483	0.169
470	0.151
445	0.125
421	0.102
399	0.080
382	0.062

* Not shown in figure.

FIGURE AND TABLE NO. 171R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF STRONTIUM ZIRCONIUM OXIDE $SrO \cdot ZrO_2$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$; α, 10^{-6} K^{-1}]

	// a-axis	// b-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	0.000	0.75
350	0.006	0.005	0.005	0.005	0.77
400	0.010	0.008	0.009	0.009	0.82
500	0.019	0.017	0.018	0.018	0.87
600	0.028	0.025	0.028	0.027	0.92
700	0.037	0.035	0.037	0.036	0.97
800	0.046	0.045	0.047	0.046	1.01
900	0.056	0.055	0.059	0.056	1.05
1000	0.067	0.066	0.070	0.067	1.10
1100	0.077	0.077	0.081	0.078	1.13
1200	0.088	0.088	0.094	0.090	1.17
1300	0.100	0.100	0.106	0.102	1.21
1400	0.112	0.112	0.119	0.114	1.24
1500	0.124	0.124	0.132	0.127	1.27
1600	0.136	0.136	0.145	0.139	1.30

REMARKS

The provisional values for the axial expansion are based on the data for pure sample. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ±7% and are represented approximately by the following equation:

// a-axis: $\Delta L/L_0 = -0.023 + 7.751 \times 10^{-5}\ T + 8.408 \times 10^{-9}\ T^2 + 3.349 \times 10^{-12}\ T^3$

// b-axis: $\Delta L/L_0 = -0.018 + 5.086 \times 10^{-5}\ T + 3.990 \times 10^{-8}\ T^2 - 7.193 \times 10^{-12}\ T^3$

// c-axis: $\Delta L/L_c = -0.019 + 5.812 \times 10^{-5}\ T + 3.650 \times 10^{-8}\ T^2 - 5.325 \times 10^{-12}\ T^3$

polycrystalline: $\Delta L/L_0 = -0.019 + 6.0619 \times 10^{-5}\ T + 2.895 \times 10^{-8}\ T^2 - 2.982 \times 10^{-12}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±7%.

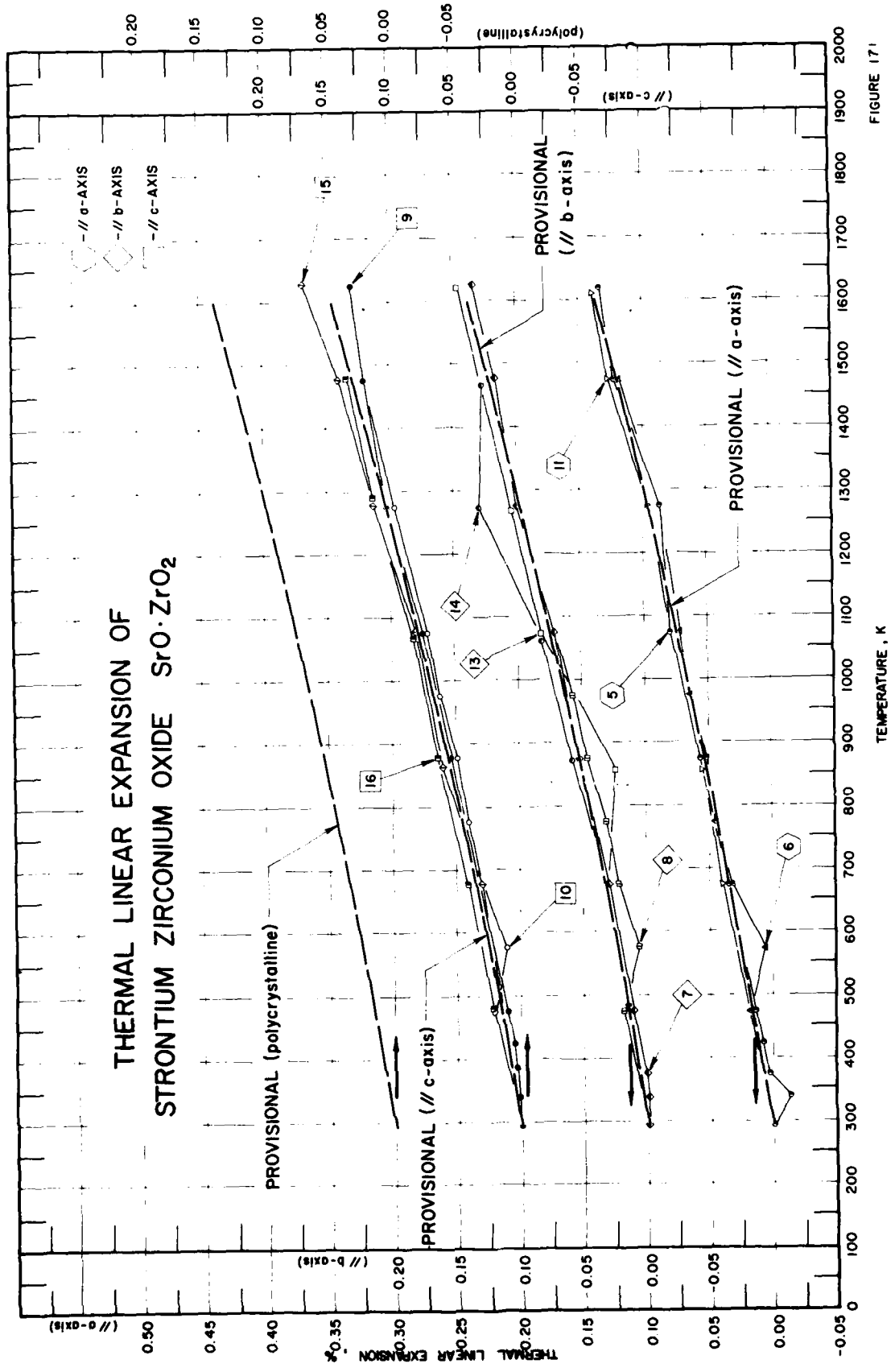

THERMAL LINEAR EXPANSION OF
STRONTIUM ZIRCONIUM OXIDE SrO·ZrO2
PROVISIONAL (polycrystalline)
PROVISIONAL (// c-axis)
PROVISIONAL (// b-axis)
PROVISIONAL (// a-axis)
// a-AXIS
// b-AXIS
// c-AXIS
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
(// a-axis)
(// b-axis)
(// c-axis)
(polycrystalline)

FIGURE 171

SPECIFICATION TABLE 171. THERMAL LINEAR EXPANSION OF STRONTIUM ZIRCONIUM OXIDE $SrO \cdot ZrO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	928	Branson, D.L.	1965	I	296-973		Specimen prepared by pressing -325 mesh powders into cylindrical shape, sintering and grinding, and shaping into pyramid ~0.25 in. high; bulk density 5.00 g cm^{-3}.
2*	935	Berezhnoi, A.S. and Belik, V.Ya.	1967		273-1473		No details given.
3*	936	Berezhnoi, A.S., Belik, V.Ya., Gavrish, A.M., and Gul'ko, N.V.	1968		298, 1473		Specimen density 5.42 g cm^3, melting point 3023 K.
4*	929	Wheildon, W.M.	1967	L	293-1373		Specimen 1/8 x 1/8 x 2 in. section cut from thick coating and diamond ground all over to dimensions, crystal form; orthorhombic; bulk density 4.71 g cm^3 porosity (total) 9.8%.
5	937	Funk, J.E., Nemeth, J., and Tinklepaugh, J.R.	1964	X	293-1620		Chemically pure $SrZrO_3$; spectrographic analysis: 0.1 Si, 0.1 Fe, 0.1 Al, 0.1 Mg; fired at 1973 K for 2 hr, bar of 4 x 1/2 x 1/2 in. dry pressed at 12,000 psi and cut into smaller bars; hot pressed at 1803 K and 3500 psi; expansion measured along a-axis.
6	937	Funk, J.E., et al.	1964	X	1473-473		The above specimen; expansion measured with decreasing temperature along a-axis.
7	937	Funk, J.E., et al.	1964	X	293-1626		Similar to the above specimen; expansion measured with increasing temperature along b-axis.
8	937	Funk, J.E., et al.	1964	X	1473-473		The above specimen; expansion measured with decreasing temperature along b-axis.
9	937	Funk, J.E., et al.	1964	X	293-1623		Similar to the above specimen; expansion measured with increasing temperature along c-axis.
10	937	Funk, J.E., et al.	1964	X	1473-473		The above specimen; expansion measured with decreasing temperature along c-axis.
11	937	Funk, J.E., et al.	1964	X	293-1610		Commercial $SrZrO_3$, spectrographic analysis, 1.0 Si, 0.1 Fe, 0.1 Al, 0.1 Mg; sintered to 1673 K for 4 hr then crushed and steel-ball milled for 2 hr; dried powder pressed in steel die at 12,000 psi into 4 x 1/2 x 1/2 in. bar, fired at 1773 K for 2 hr, then cut to 1 3/4 x 1/2 x 1/8 in. and hand ground with 600 mesh SiC paper; expansion measured along a-axis.
12	937	Funk, J.E., et al.	1964	X	1473-293		The above specimen; expansion measured with decreasing temperature along a-axis; zero-point correction -0.003%.
13	937	Funk, J.E., et al.	1964	X	293-1620		Similar to the above specimen; expansion measured with increasing temperature along b-axis.
14	937	Funk, J.E., et al.	1964	X	1467-293		The above specimen; expansion measured with decreasing temperature along b-axis; zero-point correction -0.003%.
15	937	Funk, J.E., et al.	1964	X	293-1626		Similar to the above specimen; expansion measured with increasing temperature along c-axis.
16	937	Funk, J.E., et al.	1964	X	1478-293		The above specimen; expansion measured with decreasing temperature along c-axis; zero-point correction -0.027%.

* Not shown in figure.

DATA TABLE 171. THERMAL LINEAR EXPANSION OF STRONTIUM ZIRCONIUM OXIDE $SrO \cdot ZrO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
296	0.003
593	0.262
973	0.617

CURVE 2*

T	$\Delta L/L_0$
273	-0.02
473	0.22
673	0.44
733	0.55
933	0.74
1073	0.80
1123	0.87
1273	1.00
1473	1.12

CURVE 3*

T	$\Delta L/L_0$
298	0.005
1473	1.180

CURVE 4*

T	$\Delta L/L_0$
293	0.000
323	0.032
373	0.060
423	0.103
473	0.145
523	0.189
573	0.242
623	0.290
673	0.343
723	0.393
773	0.443
823	0.492
873	0.544
923	0.595
973	0.641
1023	0.687
1073	0.734
1123	0.778
1173	0.826
1198	0.834
1223	0.852
1248	0.871

CURVE 4 (cont.)

T	$\Delta L/L_0$
1273	0.867
1323	0.889
1373	0.913

CURVE 5

T	$\Delta L/L_0$
293	0.000
340	-0.014
373	0.003
424	0.009
473	0.014
673	0.037
873	0.057
1073	0.079
1273	0.087
1473	0.122
1620	0.133

CURVE 6

T	$\Delta L/L_0$
1473	0.118
1273	0.089*
1073	0.072
973	0.063
873	0.053
773	0.045
673	0.034
573	0.007
473	0.020

CURVE 7

T	$\Delta L/L_0$
293	0.000
337	-0.001
373	0.001
473	0.011
673	0.030
873	0.052
1073	0.071
1273	0.098
1473	0.117
1626	0.133

CURVE 8

T	$\Delta L/L_0$
1473	0.115*
1273	0.096*
1073	0.070*
973	0.057
873	0.045
773	0.031
673	0.020
573	0.006
473	0.018

CURVE 9

T	$\Delta L/L_0$
293	0.000
337	0.002
373	0.003
423	0.006
473	0.011
673	0.029
873	0.054
1073	0.075
1273	0.102
1473	0.120
1623	0.130

CURVE 10

T	$\Delta L/L_0$
1473	0.120*
1273	0.097
1073	0.072
973	0.062
873	0.049
773	0.040
673	0.029*
573	0.011
473	0.021

CURVE 11

T	$\Delta L/L_0$
293	0.000*
673	0.040
856	0.055
1073	0.078*
1273	0.097
1473	0.126
1610	0.138

CURVE 12*

T	$\Delta L/L_0$
1473	0.123
1273	0.094
1073	0.077
873	0.052
673	0.033
484	0.010
293	0.000

CURVE 13

T	$\Delta L/L_0$
293	0.000*
673	0.037*
856	0.024
1072	0.081
1268	0.103
1471	0.127*
1620	0.145

CURVE 14

T	$\Delta L/L_0$
1467	0.126
1271	0.129
1060	0.081
870	0.058
669	0.032*
485	0.015
293	0.000*

CURVE 15

T	$\Delta L/L_0$
293	0.000*
674	0.031
861	0.060
1075	0.080
1276	0.113
1474	0.140
1626	0.168

CURVE 16

T	$\Delta L/L_0$
1478	0.134
1286	0.114
1066	0.081
877	0.064
674	0.040

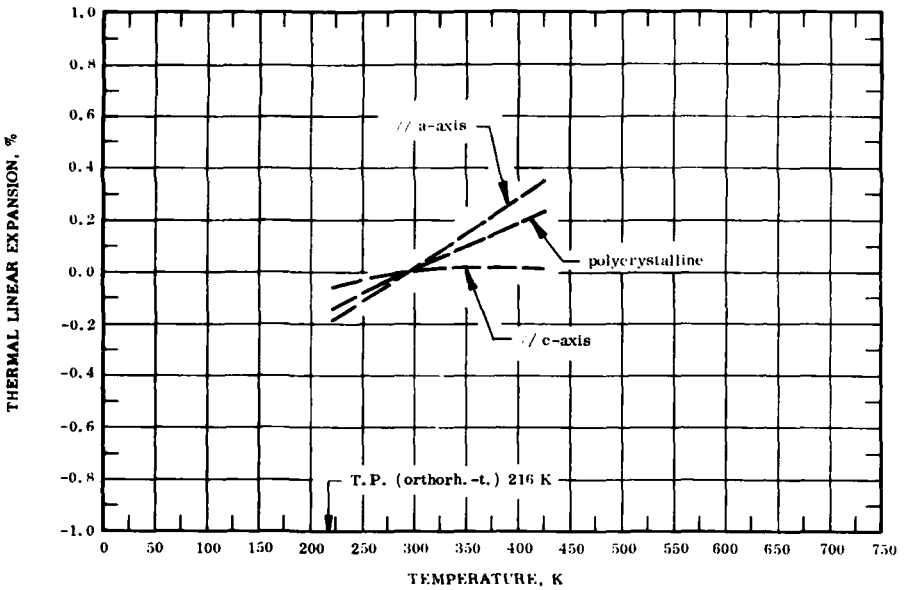
CURVE 16 (cont.)

T	$\Delta L/L_0$
480	0.022
293	0.000*

* Not shown in figure.

4. SALTS

FIGURE AND TABLE NO. 172R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF AMMONIUM DIHYDROGEN ARSENATE $NH_4H_2AsO_4$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
220	-0.182	-0.060	-0.140	19.9
250	-0.115	-0.023	-0.083	19.1
275	-0.050	-0.005	-0.035	18.5
293	0.000	0.000	0.000	18.2
325	0.080	0.006	0.055	17.9
350	0.145	0.008	0.099	17.7
375	0.213	0.008	0.143	17.7
400	0.280	0.008	0.189	17.9
425	0.345	0.011	0.233	18.1

REMARKS

The provisional values for the axial expansion are based on the data for pure sample. The values for the polycrystalline sample are calculated from the selected axial values. These values are considered accurate to within ±7% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.462 - 4.992 \times 10^{-6} T + 7.536 \times 10^{-6} T^2 - 6.947 \times 10^{-9} T^3$

// c-axis: $\Delta L/L_0 = -1.136 + 9.510 \times 10^{-3} T - 2.626 \times 10^{-5} T^2 + 2.410 \times 10^{-8} T^3$

polycrystalline: $\Delta L/L_0 = -0.695 + 3.222 \times 10^{-3} T - 4.008 \times 10^{-6} T^2 + 3.689 \times 10^{-9} T^3$

The tabulated values for the coefficeint of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

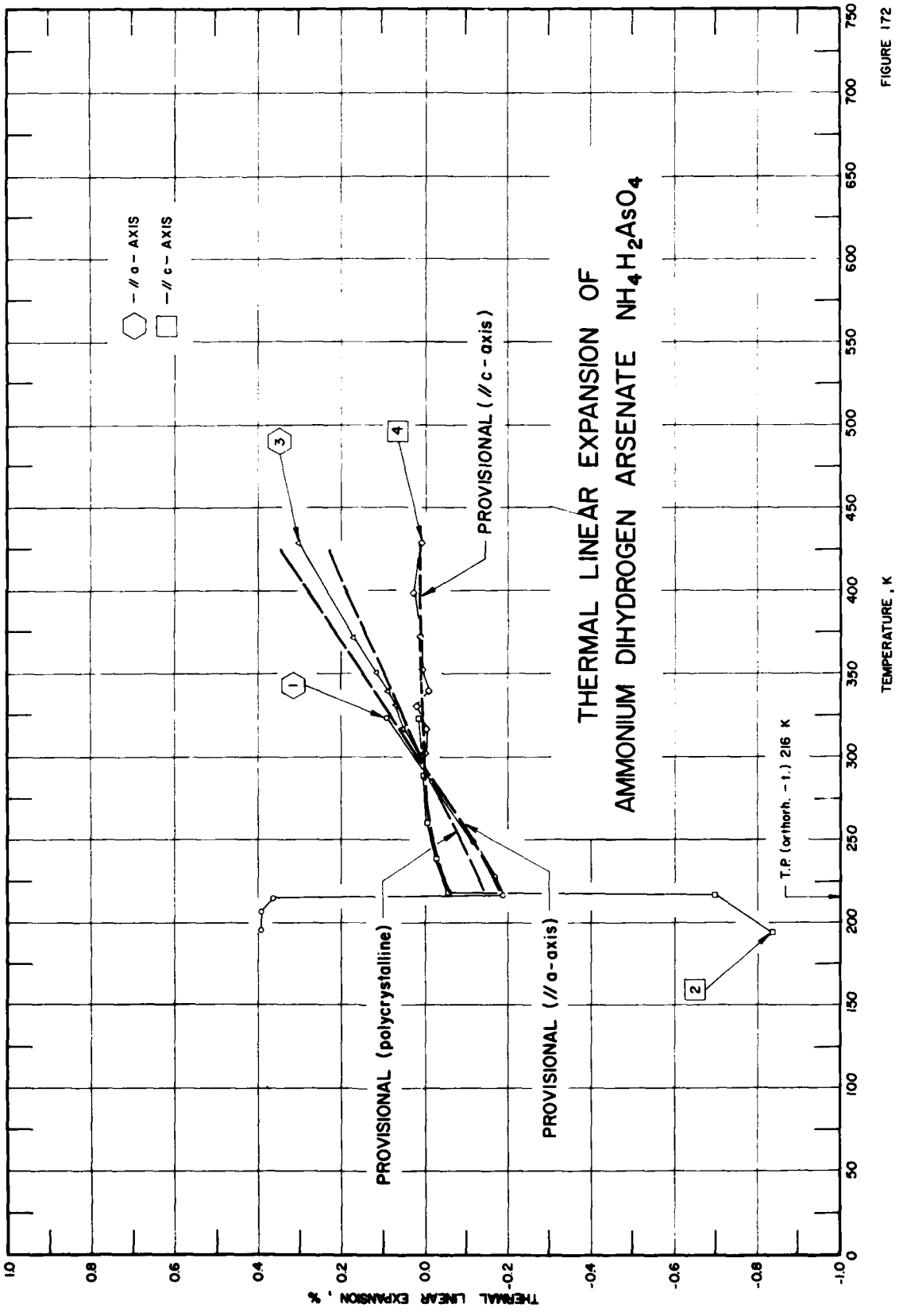

THERMAL LINEAR EXPANSION OF
AMMONIUM DIHYDROGEN ARSENATE $NH_4H_2AsO_4$
— // a - AXIS
— // c - AXIS
PROVISIONAL (// c - axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// a-axis)
T.P. (orthorh. - t.) 216 K
1
2
3
4
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750

FIGURE 172

SPECIFICATION TABLE 172. THERMAL LINEAR EXPANSION OF AMMONIUM DIHYDROGEN ARSENATE $NH_4H_2AsO_4$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	287	Cook, W.R., Jr.	1967	I	195-322		Average expansion measured along a- and b-axes of orthorhombic; crystal below the phase transition at 216 K at which lattice parameter reported for a-axis is 7.6790 Å; 7.6944 Å reported at 298 K; total contraction between 298 K and transition temperature is 21.4% along a-axis.
2	287	Cook, W.R., Jr.	1967	I	193-322		The above specimen; expansion measured along c-axis; 7.715 Å at transition temperature; 7.720 Å reported at 298 K; total contraction between these two temperatures is 6.5%.
3	288	Deshpande, V.T. and Khan, A.A.	1965	X	300-428		Crystalline specimen; prepared by evaporating heated mixture of aqueous As_2O_5 and ammonia; expansion measured along a-axis; lattice parameter reported at 326 K is 7.701 Å; 7.000 Å at 293 K determined by graphical extrapolation.
4	288	Deshpande, V.T. and Khan, A.A.	1965	X	293-427		The above specimen; expansion measured along c-axis; lattice parameter reported at 293 K is 7.716 Å.

DATA TABLE 172. THERMAL LINEAR EXPANSION OF AMMONIUM DIHYDROGEN ARSENATE $NH_4H_2AsO_4$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
195	0.39
206	0.39
214	0.36
216	-0.19
227	-0.17
248	-0.12
285	-0.02
322	0.09
CURVE 2	
193	-0.84
216	-0.70
217	-0.06
238	-0.03
260	-0.01
288	0.00
322	0.01
CURVE 3	
300	0.010
316	0.048
330	0.067
337	0.088
350	0.117
371	0.166
428	0.301
CURVE 4	
293	0.000
301	-0.002
316	-0.007
330	0.014
338	-0.011
352	0.003
372	0.007
398	0.022
427	0.001

SPECIFICATION TABLE 173. THERMAL LINEAR EXPANSION OF GALLIUM ARSENATE $GaAsO_4$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	289	Shafer, E.C. and Roy, R.	1956	X	302-697		Quartz form specimen; made by mixing δ-Ga_2O_3 and H_3AsO_4 into slurry in platinum crucible and heating to 873 K; expansion measured in (310) crystal plane; zero-point correction of 0.10% determined by graphical extrapolation.
2*	289	Shafer, E.C. and Roy, R.	1956	X	302-696		The above specimen; expansion measured in (104) crystal plane; zero-point correction of 0.10% determined by graphical extrapolation.

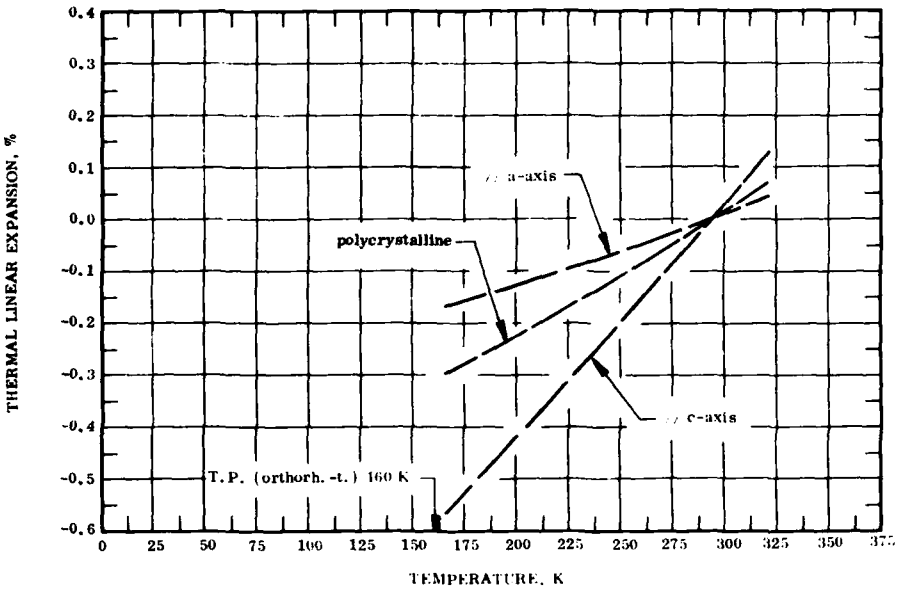
DATA TABLE 173. THERMAL LINEAR EXPANSION OF GALLIUM ARSENATE $GaAsO_4$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
302	0.04
334	0.15
398	0.25
478	0.38
587	0.55
697	0.69
CURVE 2*	
302	0.04
340	0.08
414	0.13
503	0.19
591	0.25
696	0.27

*No figure given.

FIGURE AND TABLE NO. 174R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF POTASSIUM DIDEUTERIUM ARSENATE KD_2AsO_4



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
165	-0.569	-0.163	-0.298	19.0
175	-0.528	-0.154	-0.279	19.9
200	-0.421	-0.129	-0.226	22.0
225	-0.310	-0.098	-0.169	23.6
250	-0.197	-0.064	-0.109	24.7
275	-0.082	-0.028	-0.046	25.3
293	0.000	0.000	0.000	25.6
320	0.122	0.042	0.069	25.7

REMARKS

The provisional values for the axial thermal expansion are based on the data for crystal sample. The values for the polycrystalline sample are calculated from the axial expansion values. These values are considered accurate to within ±10% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -1.036 + 1.167 \times 10^{-3} T + 1.267 \times 10^{-5} T^2 - 1.566 \times 10^{-8} T^3$

// a-axis: $\Delta L/L_0 = -0.110 - 1.748 \times 10^{-3} T + 1.047 \times 10^{-5} T^2 - 1.102 \times 10^{-8} T^3$

polycrystalline: $\Delta L/L_0 = -0.426 - 6.945 \times 10^{-4} T + 1.091 \times 10^{-5} T^2 - 1.220 \times 10^{-8} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

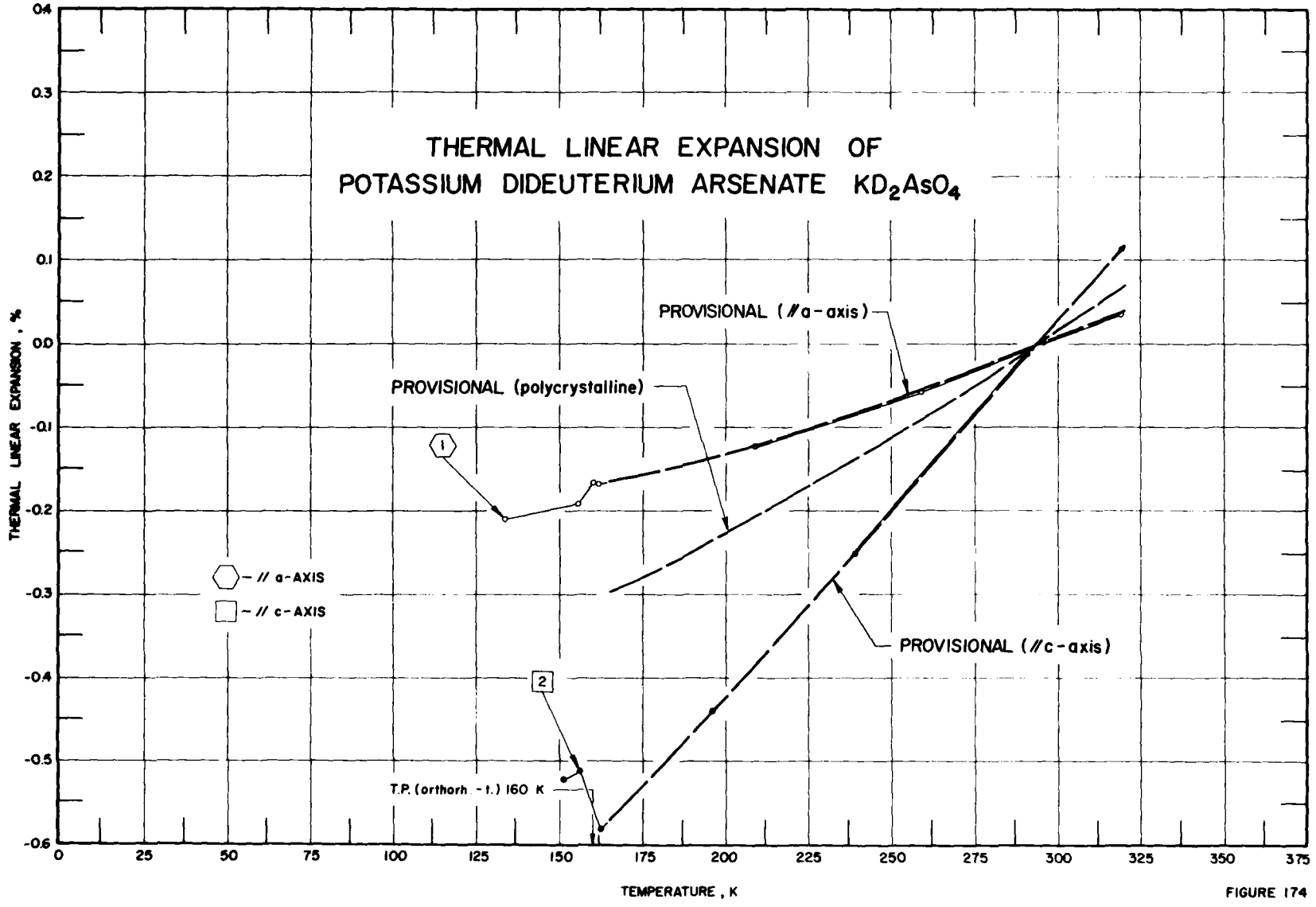

THERMAL LINEAR EXPANSION OF
POTASSIUM DIDEUTERIUM ARSENATE KD_2AsO_4
PROVISIONAL (// a - axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// c - axis)
1
2
⬡ - // a-AXIS
□ - // c-AXIS
T.P. (orthorh. - t.) 160 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375

FIGURE 174

SPECIFICATION TABLE 174. THERMAL LINEAR EXPANSION OF POTASSIUM DII EUTERIUM ARSENATE KD_2AsO_4

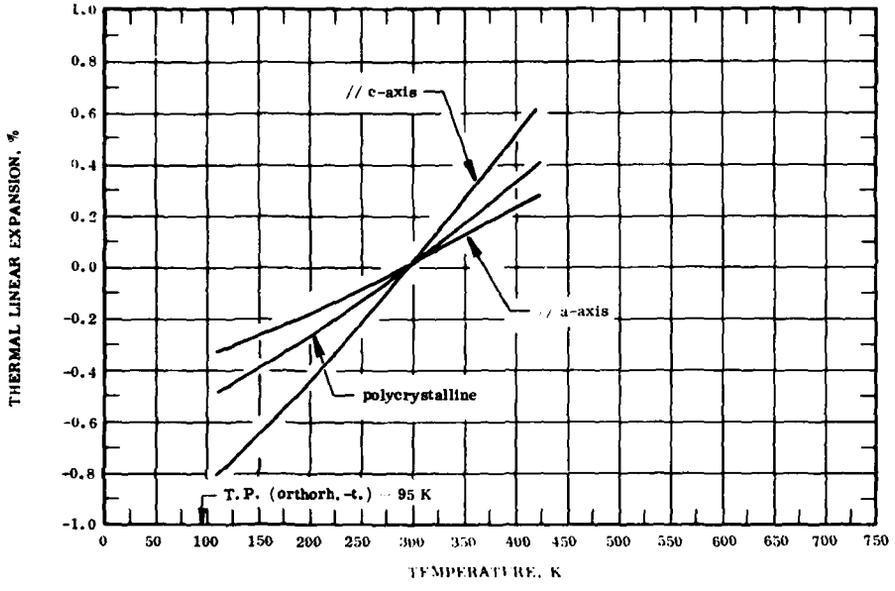
Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	287	Cook, W.R.	1967	I	134-319		Crystal specimen; transition temperature at 161 K for transformation of orthorhombic to tetragonal structure; expansion measured along a-axis for specimen 6.5 mm long; 7.6295 Å of tetragonal crystal reported at 298 K; total contraction from 298 K to 161 K is 0.183%.
2	287	Cook, W.R.	1967	I	151-319		Similar to the above specimen; expansion measured along c-axis for specimen 5.0 mm long; 7.1636 Å of tetragonal crystal reported at 298 K; total contraction from 298 K to 161 K is 0.615%.

DATA TABLE 174. THERMAL LINEAR EXPANSION OF POTASSIUM DIDEUTERIUM ARSENATE KD_2AsO_4

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
134	-0.210
156	-0.191
160	-0.166
162	-0.169
209	-0.124
259	-0.058
296	0.001
319	0.037
CURVE 2	
151	-0.522
156	-0.513
160	-0.583
196	-0.440
239	-0.250
292	-0.011
319	0.117

FIGURE AND TABLE NO. 175R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF POTASSIUM DIHYDROGEN ARSENATE KH_2AsO_4



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
110	-0.801	-0.326	-0.484	19.2
125	-0.747	-0.306	-0.453	21.4
150	-0.652	-0.269	-0.397	23.5
175	-0.549	-0.229	-0.336	25.4
200	-0.440	-0.190	-0.273	26.9
225	-0.326	-0.140	-0.202	28.3
250	-0.208	-0.090	-0.129	29.4
275	-0.088	-0.038	-0.055	30.2
293	0.000	0.000	0.000	30.7
325	0.156	0.070	0.099	31.2
350	0.277	0.127	0.177	31.5
375	0.395	0.180	0.252	31.7
400	0.512	0.240	0.331	31.9
420	0.601	0.290	0.394	32.0

REMARKS

The recommended values for the axial thermal expansion are based on the data for pure samples. The values for polycrystalline sample are calculated from the axial values. These values are considered accurate to within ±5% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -1.077 + 1.411 \times 10^{-3} T + 1.137 \times 10^{-5} T^2 - 1.242 \times 10^{-8} T^3$

// a-axis: $\Delta L/L_0 = -0.423 + 4.289 \times 10^{-4} T + 4.470 \times 10^{-6} T^2 - 3.452 \times 10^{-9} T^3$

polycrystalline: $\Delta L/L_0 = -6.361 \times 10^{-1} + 6.994 \times 10^{-4} T + 6.988 \times 10^{-6} T^2 - 6.711 \times 10^{-9} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±7%.

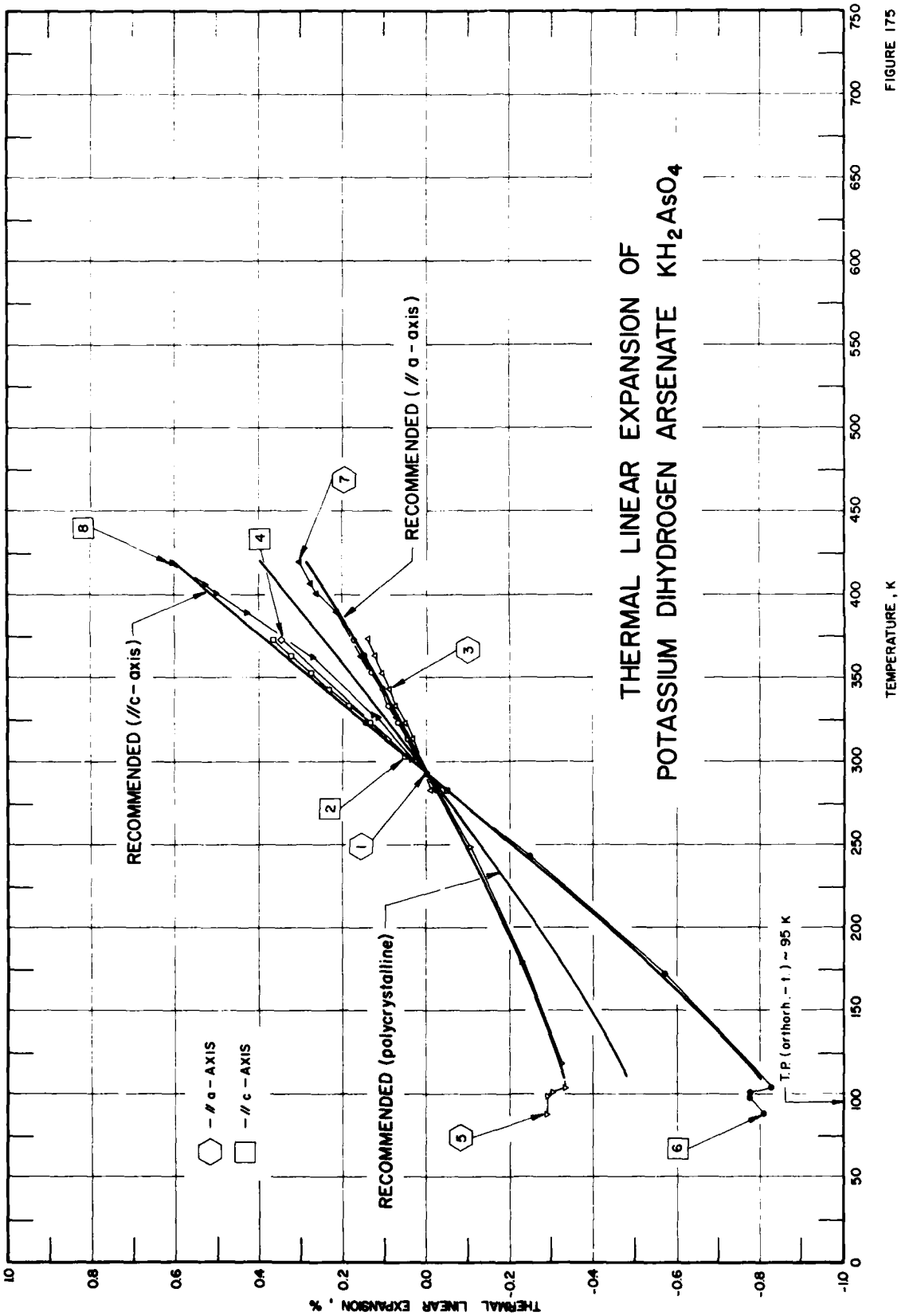

THERMAL LINEAR EXPANSION OF
POTASSIUM DIHYDROGEN ARSENATE KH_2AsO_4
RECOMMENDED (//c- axis)
RECOMMENDED (// a - axis)
RECOMMENDED (polycrystalline)
T.P. (orthorh. - t) ~ 95 K
- // a - AXIS
- // c - AXIS
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1
2
3
4
5
6
7
8

FIGURE 175

SPECIFICATION TABLE 175. THERMAL LINEAR EXPANSION OF POTASSIUM DIHYDROGEN ARSENATE KH_2AsO_4

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	290	Adhav, R.S.	1968	L	283-373	KDA	Single crystal specimen, grown in H_2O; plate about 1.5 x 3 x 20 mm, cut from single crystal; polished by 10 μ emery abrasive with isopropyl alcohol as lubricant; a layer of gold deposited on the plate face; expansion measured along x-axis; zero-point correction of -0.046.
2	290	Adhav, R.S.	1968	L	283-373	KDA	The above specimen; expansion measured along z-axis; zero-point correction of -0.097% determined by graphical interpolation.
3	290	Adhav, R.S.	1968	L	283-373	D-KDA	Single crystal specimen; grown in D_2O; plate about 1.5 x 3 x 20 mm; cut from single crystal; polish by 10 μ emery abrasive with isopropyl alcohol as lubricant; a layer of gold deposited on the plate face; expansion measured along x-axis; zero-point correction of -0.033%.
4	290	Adhav, R.S.	1968	L	283-373	D-KDA	The above specimen; expansion measured along z-axis; zero-point correction of -0.100%.
5	287	Cook, W.R., Jr.	1967	I	87-323		Crystal specimen 5.2 mm long; transition temperature at 95 K for orthorhombic to tetragonal structure; expansion measured along a-axis; 7.6295 Å at 298 K; total contraction from 298 K to transition temperature 0.342%.
6	287	Cook, W.R., Jr.	1967	I	87-323		The above specimen; expansion measured along c-axis; total contraction from 298 K to total contraction from 298 K to transition temperature 0.342%.
7	675	Deshpande, V.T. and Khan, A.A.	1965	X	291-420	KDA	Specimen prepared by neutralizing an aqueous solution of pure potassium carbonate with an aqueous solution of pure arsenic pentoxide; soln. evaporated to obtain crystals; expansion measured along a-axis; 7.6287 Å reported at 291 K; 7.6288 Å reported at 291 K; 7.6288 Å at 293 K determined by graphical interpolation.
8	675	Deshpande, V.T. and Khan, A.A.	1965	X	291-420	KDA	The above specimen; expansion measured along c-axis; 7.1612 Å reported at 291 K; 7.1615 Å at 293 K determined by graphical interpolation.

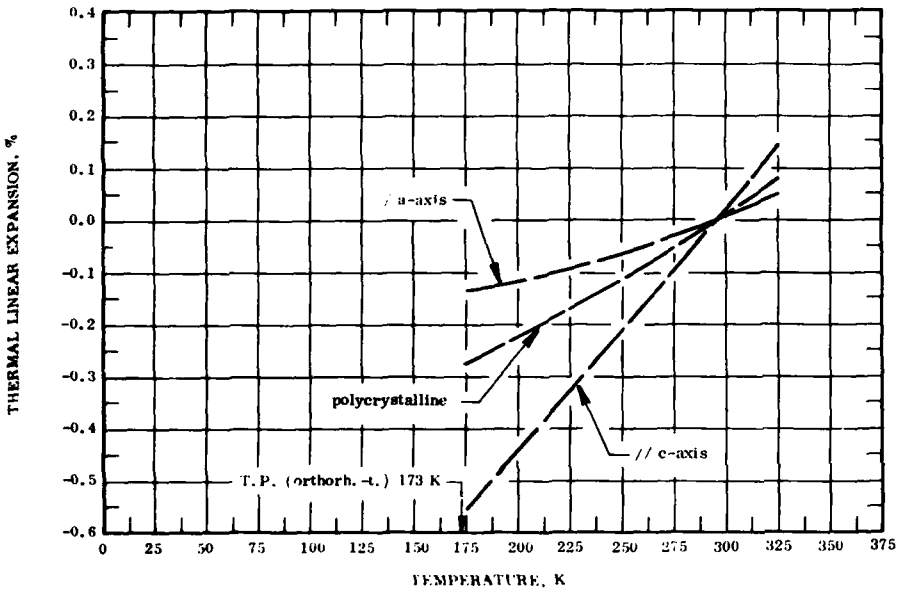
DATA TABLE 175. THERMAL LINEAR EXPANSION OF POTASSIUM DIHYDROGEN ARSENATE KH_2AsO_4

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
283	-0.021
293	0.000
303	0.023
313	0.045
323	0.070
333	0.092
343	0.107
353	0.131
363	0.153
373	0.174
CURVE 2	
283	-0.050
303	0.051
323	0.139
333	0.185
343	0.232
353	0.275
363	0.324
373	0.369
CURVE 3	
283	-0.012
293	0.000*
303	0.021*
313	0.037
323	0.051
333	0.067
343	0.088
353	0.107
363	0.125
373	0.140
CURVE 4	
283	-0.042*
293	0.000*
303	0.052*
313	0.094
323	0.136*
373	0.347
CURVE 5	
87	-0.287
99	-0.289
102	-0.301
104	-0.331
118	-0.321
179	-0.231
247	-0.102
323	0.066*
CURVE 6	
87	-0.808
97	-0.777
101	-0.778
104	-0.830
172	-0.570
243	-0.249
290	-0.015
323	0.143
CURVE 7	
291	-0.0013*
300	0.0157
302	0.0144*
327	0.0734
328	0.0682*
363	0.1599
390	0.2163
402	0.2674
407	0.2805
420	0.3094
CURVE 8	
291	-0.0042*
300	0.0209*
302	0.0307
327	0.1173
328	0.1229
363	0.2737
390	0.4273
402	0.5041
407	0.5292
420	0.6060

* Not shown in figure.

FIGURE AND TABLE NO. 176R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF RUBIDIUM DIDEUTERIUM ARSENATE RbD_2AsO_4



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
175	-0.556	-0.138	-0.277	18.5
200	-0.444	-0.119	-0.227	21.4
225	-0.326	-0.094	-0.171	23.5
250	-0.206	-0.063	-0.111	25.0
275	-0.085	-0.028	-0.047	26.0
293	0.000	0.000	0.000	26.6
325	0.144	0.054	0.084	27.3

REMARKS

The provisional values for the axial thermal expansion are based on the data for crystalline sample. The values for polycrystalline sample are calculated from the axial values. These values are considered accurate to within +10% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -0.923 - 1.097 \times 10^{-3} T + 2.383 \times 10^{-5} T^2 - 3.185 \times 10^{-8} T^3$

// a-axis: $\Delta L/L_0 = -0.001 - 2.522 \times 10^{-3} T + 1.192 \times 10^{-5} T^2 - 1.123 \times 10^{-8} T^3$

polycrystalline: $\Delta L/L_0 = -0.341 - 1.581 \times 10^{-3} T + 1.376 \times 10^{-5} T^2 - 1.497 \times 10^{-8} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

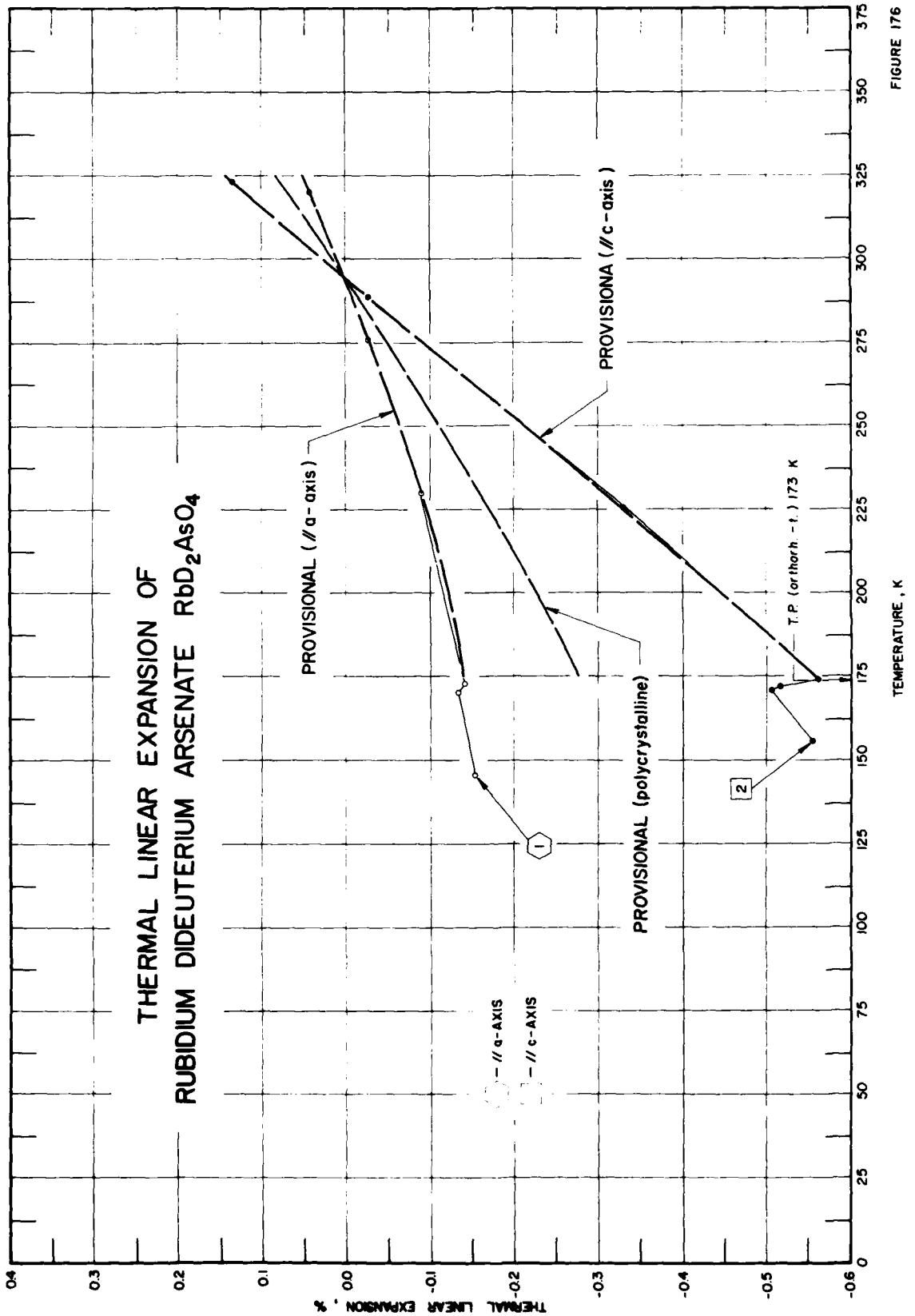

THERMAL LINEAR EXPANSION OF
RUBIDIUM DIDEUTERIUM ARSENATE RbD_2AsO_4
PROVISIONAL (// a- axis)
PROVISIONA (// c - axis)
PROVISIONAL (polycrystalline)
T.P. (orthorh - t.) 173 K
// a-AXIS
// c-AXIS
1
2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375

FIGURE 176

SPECIFICATION TABLE 176. THERMAL LINEAR EXPANSION OF RUBIDIUM DIDEUTERIUM ARSENATE RbD_2AsO_4

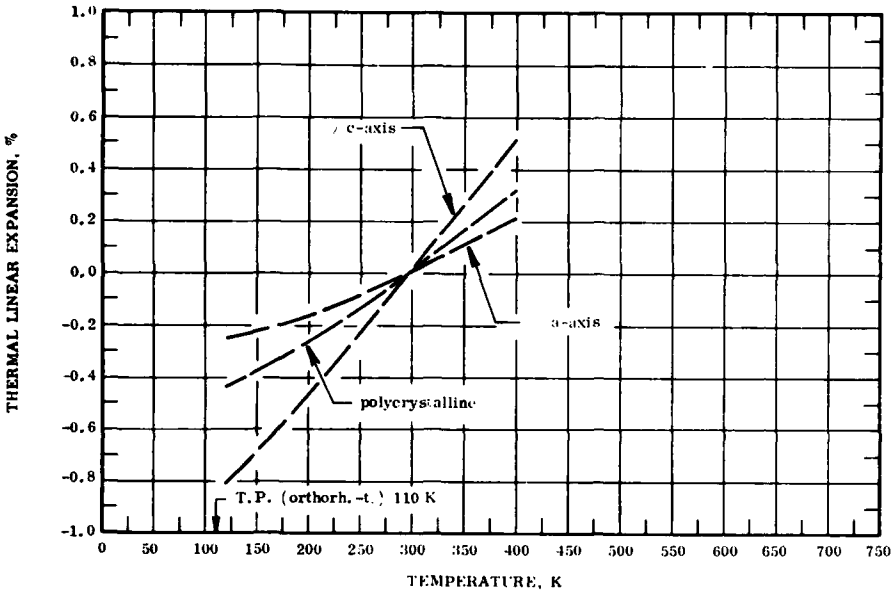
Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	287	Cook, W. R.	1967	I	146-320		Crystal specimen; transition temperature at 173 K from transformation of orthorhombic to tetragonal structure; expansion measured along a-axis for specimen 2.4 mm long; 7.8063 Å of tetragonal crystal reported at 298 K; total contraction from 298 K to 173 K is 0.145%.
2	287	Cook, W. R.	1967	I	156-323		Similar to the above specimen; expansion measured along c-axis for specimen 2.5 mm long; 7.4674 Å of tetragonal crystal reported at 298 K; total contraction from 298 K to 173 K is 0.614%.

DATA TABLE 176. THERMAL LINEAR EXPANSION OF RUBIDIUM DIDEUTERIUM ARSENATE RbD_2AsO_4

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
146	-0.152
170	-0.131
173	-0.140
230	-0.090
276	-0.026
320	0.041
CURVE 2	
156	-0.555
171	-0.508
172	-0.517
174	-0.564
226	-0.330
288	-0.027
323	0.133

FIGURE AND TABLE NO. 177R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF RUBIDIUM DIHYDROGEN ARSENATE RbH_2AsO_4



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
120	-0.805	-0.256	-0.439	18.2
150	-0.685	-0.226	-0.379	21.4
175	-0.576	-0.196	-0.323	23.7
200	-0.461	-0.161	-0.261	25.7
225	-0.341	-0.121	-0.194	27.2
250	-0.217	-0.079	-0.125	28.4
275	-0.091	-0.034	-0.053	29.2
293	0.000	0.000	0.000	29.6
325	0.160	0.062	0.095	30.0
350	0.284	0.112	0.169	30.1
375	0.402	0.162	0.242	30.1
400	0.516	0.210	0.312	30.1

REMARKS

The provisional values for the axial thermal expansion are based on the data for pure sample. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ±7% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -1.118 + 1.215 \times 10^{-3} T + 1.352 \times 10^{-5} T^2 - 1.587 \times 10^{-8} T^3$

// a-axis: $\Delta L/L_0 = -0.274 - 6.246 \times 10^{-4} T + 7.351 \times 10^{-6} T^2 - 6.900 \times 10^{-9} T^3$

polycrystalline: $\Delta L/L_0 = -0.556 - 7.737 \times 10^{-6} T + 9.414 \times 10^{-6} T^2 - 9.914 \times 10^{-9} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

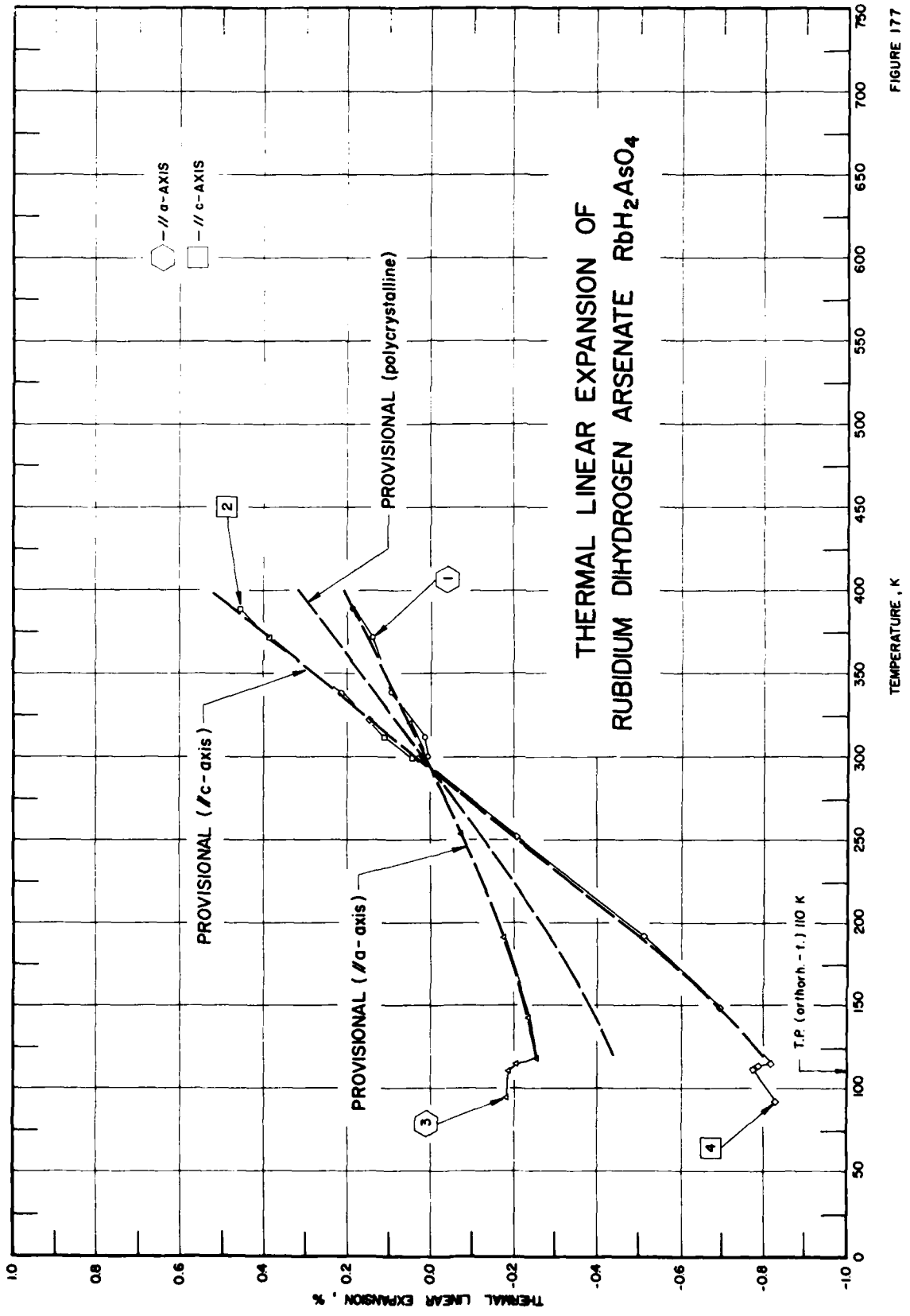

THERMAL LINEAR EXPANSION OF
RUBIDIUM DIHYDROGEN ARSENATE RbH_2AsO_4
// a-AXIS
// c-AXIS
PROVISIONAL (polycrystalline)
PROVISIONAL (// c-axis)
PROVISIONAL (// a-axis)
T.P. (orthorh. - t.) 110 K
1
2
3
4
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.0
0.8
0.6
0.4
0.2
0.0
-.2
-.4
-.6
-.8
-1.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750

FIGURE 177

SPECIFICATION TABLE 177. THERMAL LINEAR EXPANSION OF RUBIDIUM DIHYDROGEN ARSENATE RbH_2AsO_4

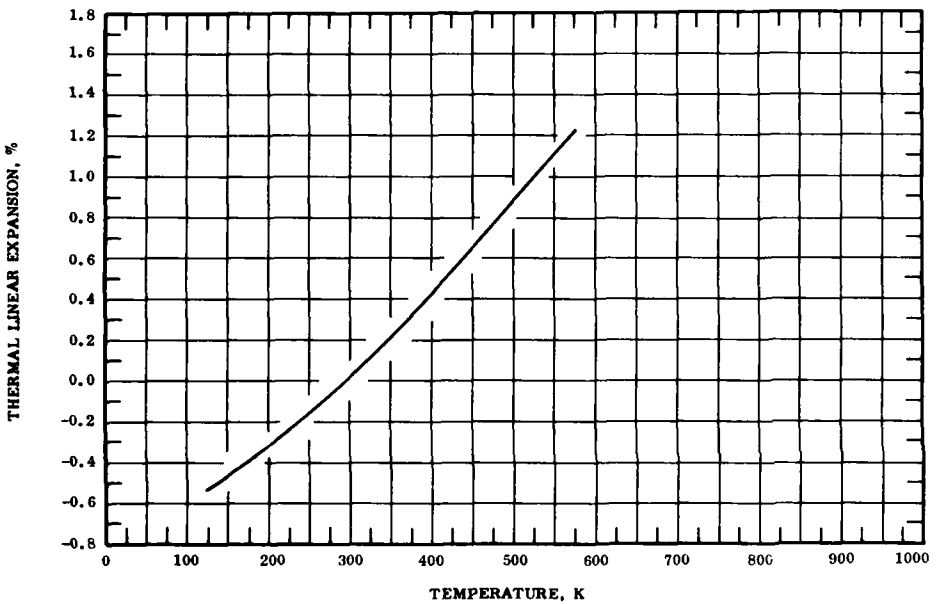
Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	291	Deshpande, V.T., Khan, A.A., and Pardiker, P.G.	1967	X	300-388		Expansion measured using CuKα radiation along a-axes; lattice parameter reported at 300.7 K is 7.7960 Å.
2	291	Deshpande, V.T., et al.	1967	X	300-388		The above specimen; expansion measured along c-axis; lattice parameter reported at 300.7 K is 7.4747 Å.
3	287	Cook, W.R.	1967	I	95-320		Crystal specimen; transition temperature at 110 K for transformation from orthorhombic to tetragonal structure; expansion measured along a-axis for specimen 2.8 mm long; 7.7933 Å for tetragonal structure reported at 298 K; total contraction from 298 K to 110 K is 0.264%.
4	287	Cook, W.R.	1967	I	93-323		Similar to the above specimen; expansion measured along c-axis for specimen 3.5 mm long; 7.4671 Å for tetragonal structure reported at 298 K; total contraction from 298 K to 110 K is 0.873%.

DATA TABLE 177. THERMAL LINEAR EXPANSION OF RUBIDIUM DIHYDROGEN ARSENATE RbH_2AsO_4

[Temperature, T K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
300.7	0.006
312.2	0.017
337.7	0.099
371.2	0.142
388.7	0.188
CURVE 2	
300.7	0.044
312.2	0.112
337.7	0.218
371.2	0.387
388.7	0.459
CURVE 3	
95	-0.180
112	-0.186
116	-0.204
117	-0.252
143	-0.235
191	-0.172
254	-0.071
320	0.049
CURVE 4	
93	-0.828
112	-0.777
114	-0.785
115	-0.819
147	-0.692
191	-0.506
252	-0.203
299	0.030
323	0.148

FIGURE AND TABLE NO. 178R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SODIUM BROMATE $NaBrO_3$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
125	-0.529	24.3
150	-0.465	26.7
175	-0.390	28.9
200	-0.320	31.0
250	-0.156	34.8
293	0.000	37.6
350	0.224	40.8
400	0.435	43.0
450	0.655	44.7
500	0.880	45.9
550	1.111	46.5
575	1.228	46.6

REMARKS

The recommended values are based on the data for pure sample and are considered accurate to within ±3%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.749 + 1.049 \times 10^{-3}\, T + 6.184 \times 10^{-6}\, T^2 - 3.530 \times 10^{-9}\, T^3$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ±5%.

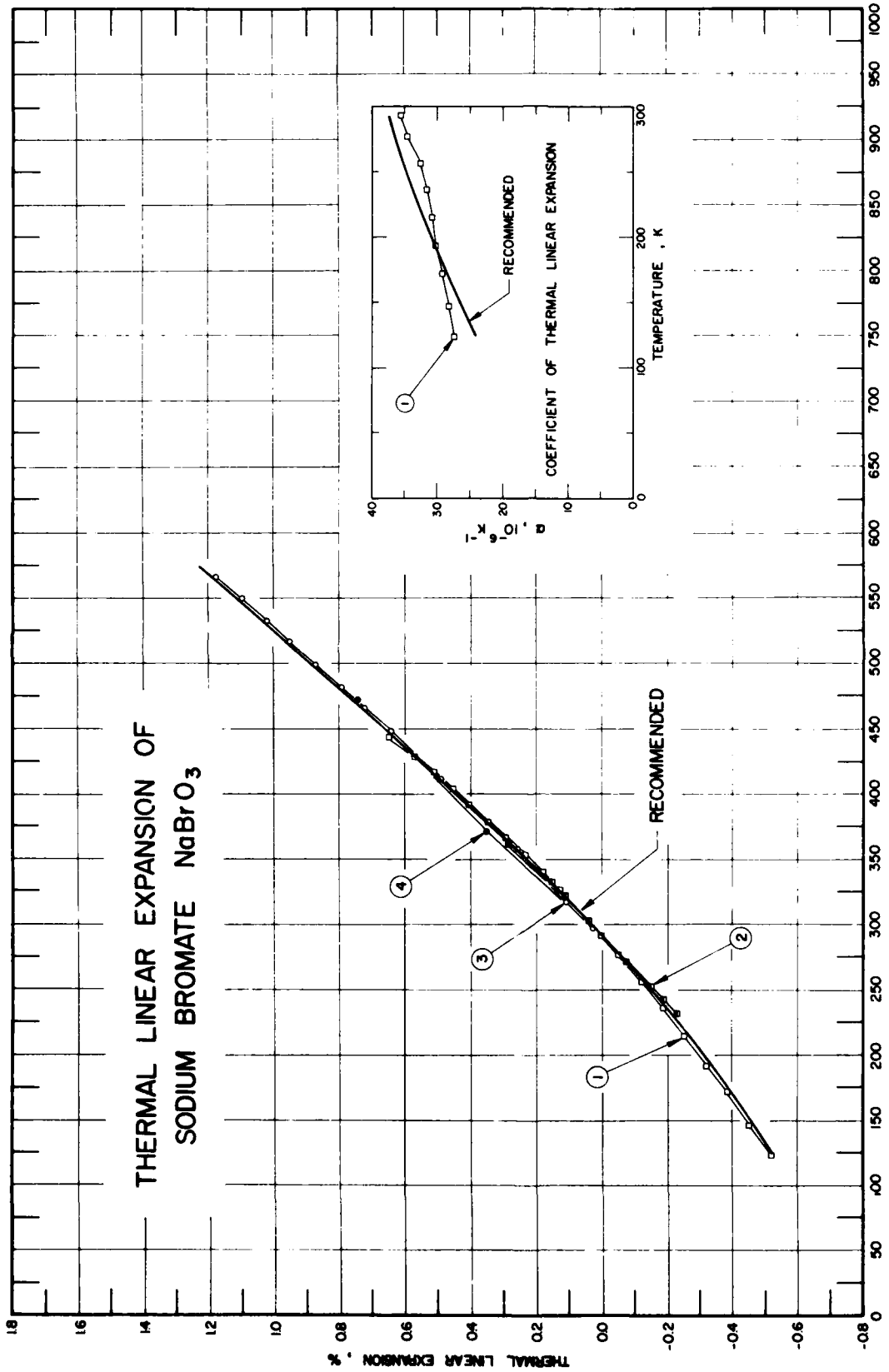

THERMAL LINEAR EXPANSION OF
SODIUM BROMATE NaBrO3
RECOMMENDED
1
2
3
4
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
α , 10⁻⁶ K⁻¹
TEMPERATURE , K

FIGURE 178

SPECIFICATION TABLE 178. THERMAL LINEAR EXPANSION OF SODIUM BROMATE $NaBrO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	967	Ganesan, S.	1959	I	124-444		Crystal grown from solution; crystalline pyramids cut to 0.493 and 0.418 cm high used as specimens.
2	968	Mason, W.P.	1946		233-363		Crystal of sodium bromate grown from saturated water solution by slowly reducing temperature and deposition salt on a prepared seed; zero-point correction 0.018%.
3	969	Sharma, S.S.	1950	I	300-566		Ground right pyramid specimen, 0.2870 cm long; zero-point correction 0.0277%.
4	970	Tkhy, C.T.L. and Filatov, S.K.	1972	X	293-573		X-ray diffraction patterns were recorded in air under CuKα radiation in DRON-1 x-ray diffractometer with FRV-1100 high-temperature attachment; lattice parameter measured at 293 K is 6.703 Å.

DATA TABLE 178. THERMAL LINEAR EXPANSION OF SODIUM BROMATE $NaBrO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 2 (cont.)		CURVE 3 (cont.)	
124.2	-0.520	428.0	0.570	343	0.197*	500.6	0.8747
147.4	-0.455	433.6	0.597*	353	0.239*	517.4	0.9513
171.2	-0.387	444.7	0.652	363	0.282	533.9	1.0279
193.7	-0.320					550.2	1.1044
215.2	-0.255	CURVE 2		CURVE 3		566.4	1.1809
236.4	-0.189						
257.8	-0.120	233	-0.232	299.8	0.0277	CURVE 4	
277.3	-0.055	243	-0.196	319.6	0.1053		
293.0	0.000	253	-0.156	339.0	0.1827*	293	0.000*
326.4	0.123	263	-0.116*	358.0	0.2599	373	0.358
340.9	0.180	273	-0.079	376.8	0.3371*	473	0.746
354.6	0.238	283	-0.040*	395.3	0.4141*	573	1.581
367.5	0.294	293	-0.000*	413.6	0.4911		
379.7	0.347	303	0.040	431.6	0.5679*		
392.4	0.404	313	0.077*	449.2	0.6447		
404.5	0.459	323	0.117	466.6	0.7214		
416.2	0.513	333	0.156	483.7	0.7981		

DATA TABLE 178. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM BROMATE $NaBrO_3$

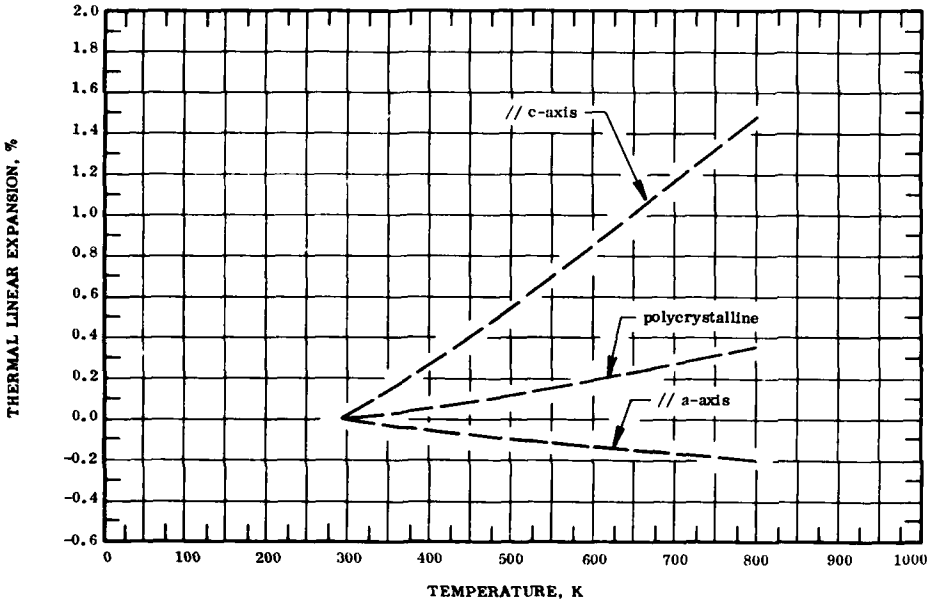
[Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\ K^{-1}$]

T	α	T	α
CURVE 1‡		CURVE 1 (cont.)‡	
124.2	27.43	404.5	46.02*
147.4	28.26	416.2	47.30*
171.2	29.16	428.0	47.96*
193.7	30.11	433.6	48.65*
215.2	30.77	444.7	50.08*
236.4	31.48		
257.8	32.59		
277.3	34.60		
293.0	35.60		
326.4	37.74*		
340.9	41.54*		
354.6	43.10*		
367.5	43.38*		
379.7	44.23*		
392.4	44.81*		

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 179R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF CALCIUM CARBONATE $CaCO_3$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	4.0
350	0.137	-0.031	0.025	4.9
400	0.266	-0.056	0.051	5.6
450	0.403	-0.080	0.081	6.3
500	0.545	-0.101	0.114	7.0
550	0.695	-0.121	0.150	7.4
600	0.846	-0.140	0.189	7.9
650	1.002	-0.157	0.229	8.3
700	1.160	-0.173	0.271	8.6
750	1.320	-0.187	0.315	8.8
800	1.480	-0.201	0.359	8.9

REMARKS

The provisional values are based on the data for pure samples. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ±7% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -0.482 + 8.792 \times 10^{-4}\ T + 2.997 \times 10^{-6}\ T^2 - 1.287 \times 10^{-9}\ T^3$

// a-axis: $\Delta L/L_0 = 0.208 - 8.614 \times 10^{-4}\ T + 5.650 \times 10^{-7}\ T^2 - 1.586 \times 10^{-10}\ T^3$

polycrystalline: $\Delta L/L_0 = -0.023 - 2.806 \times 10^{-4}\ T + 1.379 \times 10^{-6}\ T^2 - 5.396 \times 10^{-10}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±7%.

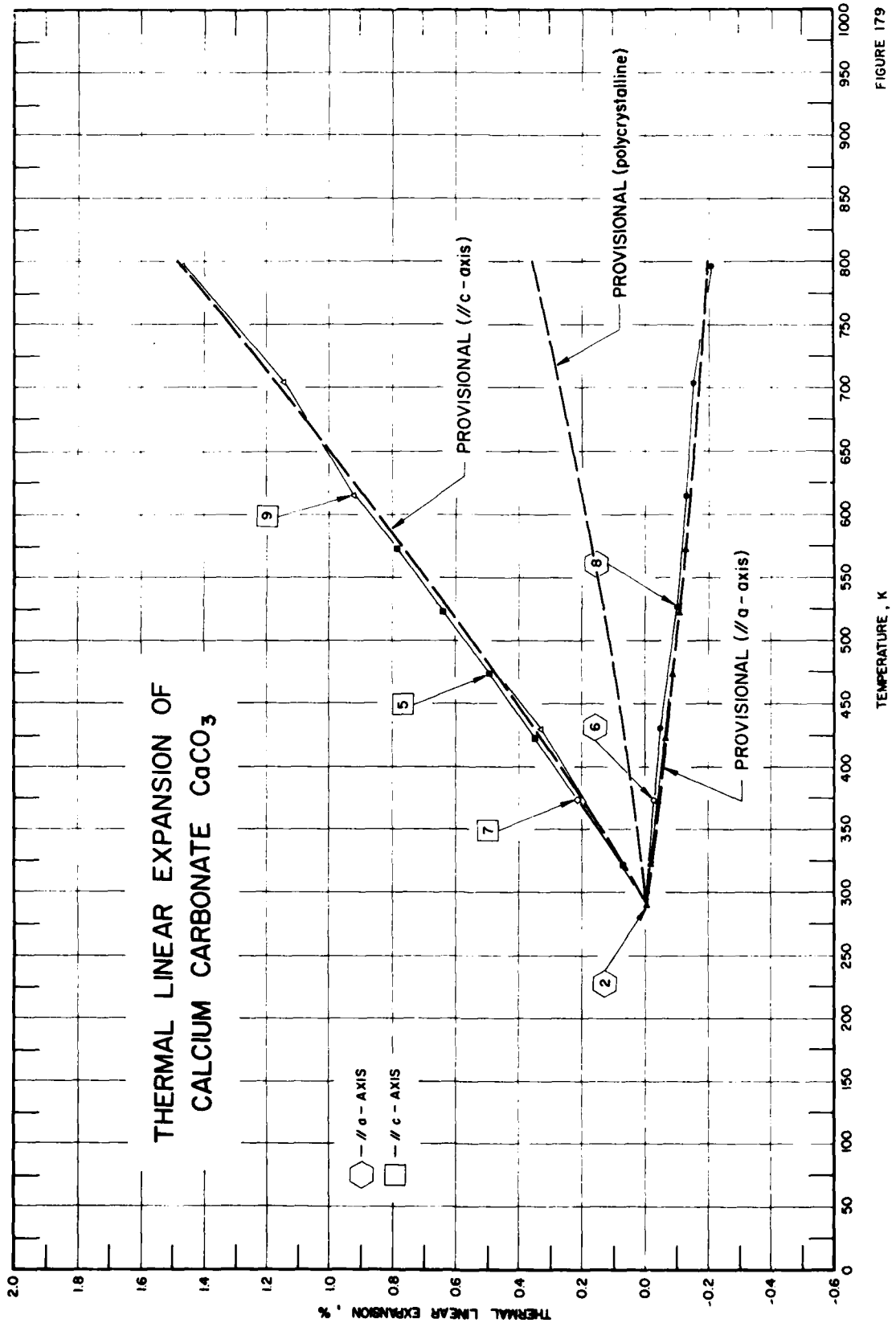

THERMAL LINEAR EXPANSION OF
CALCIUM CARBONATE $CaCO_3$
// a - AXIS
// c - AXIS
PROVISIONAL (// c - axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// a - axis)
2
5
6
7
8
9
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 179

SPECIFICATION TABLE 179. THERMAL LINEAR EXPANSION OF CALCIUM CARBONATE $CaCO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	88	Ohba, H., Hiragushi, K., and Nakashima, C.	1965	X	293-1073		Decomposed product of dolomite $CaMg(CO_3)_2$ in air; interplanar spacing reported at 293.2 K is 3.035 Å for d (014).
2	530	Austin, J.B., Saini, H., Weigle, J., and Pierce, R.H.H.	1940	I	291-573		Crystal of calcite; 0.06 MnO, 0.03 MgO, 0.01 Fe; a large clear crystal selected from Big Timber, Montana; small pieces carefully cut from this block; expansion measured parallel to a-axis; perpendicular to $(11\bar{2})$.
3*	530	Austin, J.B., et al.	1940	I	291-573		The above specimen; expansion measured perpendicular to (011).
4	530	Austin, J.B., et al.	1940	I	291-573		The above specimen; expansion measured perpendicular to rhombohedral face (211) [or (100)].
5	530	Austin, J.B., et al.	1940	I	291-573		The above specimen; expansion measured parallel to c-axis, perpendicular to (111).
6	530	Austin, J.B., et al.	1940	X	291,373		The above specimen; expansion measured parallel to a-axis, perpendicular to $(11\bar{2})$.
7	530	Austin, J.B., et al.	1940	X	291,373		The above specimen; expansion measured parallel to c-axis, perpendicular to (111).
8	719	Rao, K.V.K., Naidu, S.V.N., and Murthy, K.S.	1968	X	301-797		Powder specimen obtained by crushing very clear crystal of calcite; aluminum used as standard to estimate specimen temperature; lattice parameter measured along a-axis; 4.9887 Å reported at 301 K; 4.9888 Å at 293 K determined by graphical extrapolation; data on coefficient of linear expansion also reported.
9	719	Rao, K.V.K., et al.	1968	X	301-797		The above specimen; lattice parameter measured along c-axis; 17.0623 Å reported at 301 K; 17.0590 Å at 293 K determined by graphical extrapolation; data on coefficient of linear expansion also reported.

* Not shown in figure.

DATA TABLE 179. THERMAL LINEAR EXPANSION OF CALCIUM CARBONATE $CaCO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
373	0.065
473	0.197
573	0.296
673	0.461
773	0.593
873	0.724
973	0.823
1073	0.988
CURVE 2	
291	0.001
323	-0.014
373	-0.038
423	-0.062
CURVE 2 (cont.)	
473	-0.086
523	-0.109
573	-0.131
CURVE 3*	
291	0.000
323	0.001
373	0.002
423	0.006
473	0.011
523	0.019
573	0.026
CURVE 4	
291	-0.002
323	0.034
373	0.090
423	0.149
473	0.210
523	0.273
573	0.338
CURVE 5	
291	-0.005*
323	0.075
373	0.207
423	0.349
473	0.494
523	0.640
CURVE 5 (cont.)	
573	0.787
CURVE 6	
291	0.001*
373	-0.027
CURVE 7	
291	0.005*
373	0.214
CURVE 8	
301	-0.002
431	-0.050
CURVE 8 (cont.)	
527	-0.102
615	-0.124
705	-0.154
797	-0.208
CURVE 9	
301	0.019
431	0.331
527	0.631
615	0.927
705	1.151
797	1.471

DATA TABLE 179. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CALCIUM CARBONATE $CaCO_3$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 8*	
323	-3.76
363	-3.66
403	-3.86
443	-3.86
483	-3.91
523	-4.11
563	-4.16
603	-4.21
643	-4.46
683	-4.46
723	-4.66
743	-4.81
CURVE 9*	
323	25.64
363	26.23
CURVE 9 (cont.)*	
403	26.67
443	27.54
483	27.98
523	28.57
563	29.30
603	30.04
643	30.62
683	30.91
723	31.35
743	31.94

* Not shown in figure.

SPECIFICATION TABLE 180. THERMAL LINEAR EXPANSION OF COBALT CARBONATE $CoCO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	531	Moreau, R.	1967	X	291-553		Pure, anhydrous specimen; prepared in aqueous solution from metal salts and $NaHCO_3$ solution; expansion measured along a-axis; lattice parameter reported at 291.2 K is 4.647 kX; 4.647 kX at 293.2 K determined by graphical interpolation.
2*	531	Moreau, R.	1967	X	291-553		The above specimen; expansion measured along c-axis; lattice parameter reported at 291.2 K is 14.924 kX; 14.925 kX at 293.2 K determined by graphical interpolation.

DATA TABLE 180. THERMAL LINEAR EXPANSION OF COBALT CARBONATE $CoCO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
291.2	0.000
333.2	0.043
381.2	0.054
403.2	0.064
453.2	0.107
474.2	0.129
527.2	0.172
553.2	0.215
CURVE 2*	
291.2	-0.007
333.2	0.234
381.2	0.342
403.2	0.415
453.2	0.636
474.2	0.737
527.2	0.925
553.2	1.172

* No figure given.

SPECIFICATION TABLE 181. THERMAL LINEAR EXPANSION OF IRON CARBONATE $FeCO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	531	Moreau, R.	1967	X	293-572		Pure, anhydrous specimen; prepared in aqueous solutions from metal salt and $NaHCO_3$ solution; expansion measured using CuK_α or CoK_α radiation along a-axis; lattice parameter reported at 293.2 K is 4.678 kX.
2*	531	Moreau, R.	1967	X	293-572		The above specimen; expansion measured along c-axis; lattice parameter reported at 293.2 K is 15.341 kX.

DATA TABLE 181. THERMAL LINEAR EXPANSION OF IRON CARBONATE $FeCO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2 (cont.)*	
293	0.000	472	0.417
339	0.036	513	0.495
383	0.045	543	0.521
412	0.083	572	0.652
443	0.077		
472	0.107		
513	0.132		
543	0.150		
572	0.132		
CURVE 2*			
293	0.000		
339	0.065		
383	0.156		
412	0.319		
443	0.326		

* No figure given.

SPECIFICATION TABLE 182. THERMAL LINEAR EXPANSION OF MAGNESIUM CARBONATE $MgCO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	532	Rao, K.V.K. and Murthy, K.S.	1969	X	303-688		Specimen prepared from clear crystalline mineral; powder pattern showed no extra lines due to impurities; expansion measured along a-axis; lattice parameter reported at 303.2 K is 4.6342 Å; 4.6338 Å at 293.2 K determined by graphical extrapolation.
2*	532	Rao, K.V.K. and Murthy, K.S.	1969	X	303-688		The above specimen; expansion measured along c-axis; lattice parameter reported at 303.2 K is 15.0245 Å; 15.0217 Å at 293.2 K determined by graphical extrapolation.

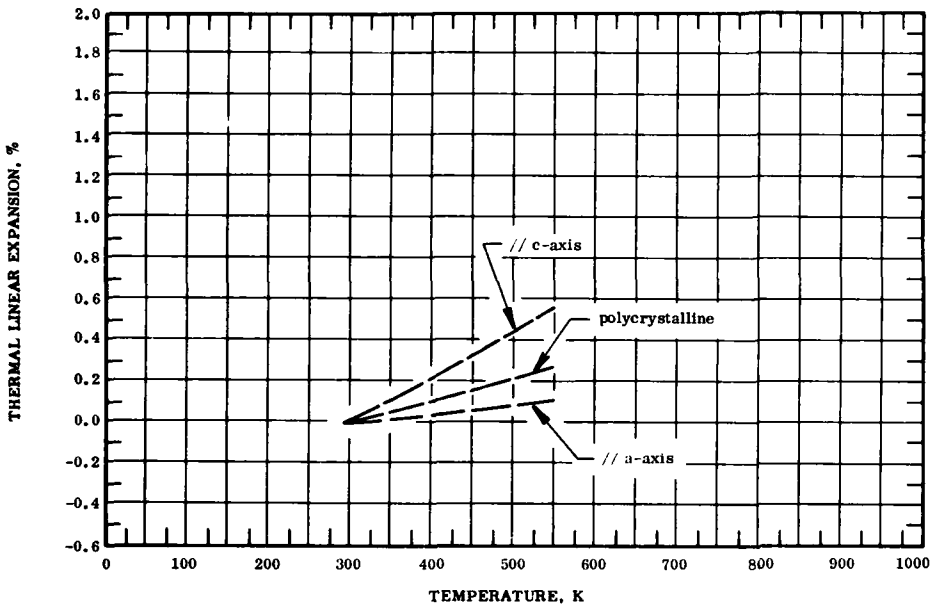
DATA TABLE 182. THERMAL LINEAR EXPANSION OF MAGNESIUM CARBONATE $MgCO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
303	0.008
362	0.053
438	0.135
490	0.185
540	0.202
588	0.228
688	0.292
CURVE 2*	
303	0.018
362	0.125
438	0.328
490	0.464
540	0.546
588	0.670
688	0.878

* No figure given.

FIGURE AND TABLE NO. 183R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF MANGANESE CARBONATE $MnCO_3$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, ϵ; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	9.3
350	0.119	0.022	0.054	9.5
400	0.225	0.040	0.102	9.6
450	0.335	0.059	0.151	10.1
500	0.444	0.082	0.203	10.9
550	0.559	0.110	0.260	11.7

REMARKS

The provisional values for the axial thermal expansion are based on the data for pure samples. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ±7% and are represented approximately by the following equations:

$$\underline{//\ c\text{-axis}}: \quad \Delta L/L_0 = -0.595 + 2.047 \times 10^{-3}\, T - 2.310 \times 10^{-7}\, T^2 + 5.857 \times 10^{-10}\, T^3$$

$$\underline{//\ a\text{-axis}}: \quad \Delta L/L_0 = -0.231 + 1.395 \times 10^{-3}\, T - 2.830 \times 10^{-6}\, T^2 + 2.580 \times 10^{-9}\, T^3$$

$$\underline{\text{polycrystalline}}: \quad \Delta L/L_0 = -0.362 + 1.677 \times 10^{-3}\, T - 2.099 \times 10^{-6}\, T^2 + 2.009 \times 10^{-9}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±7%.

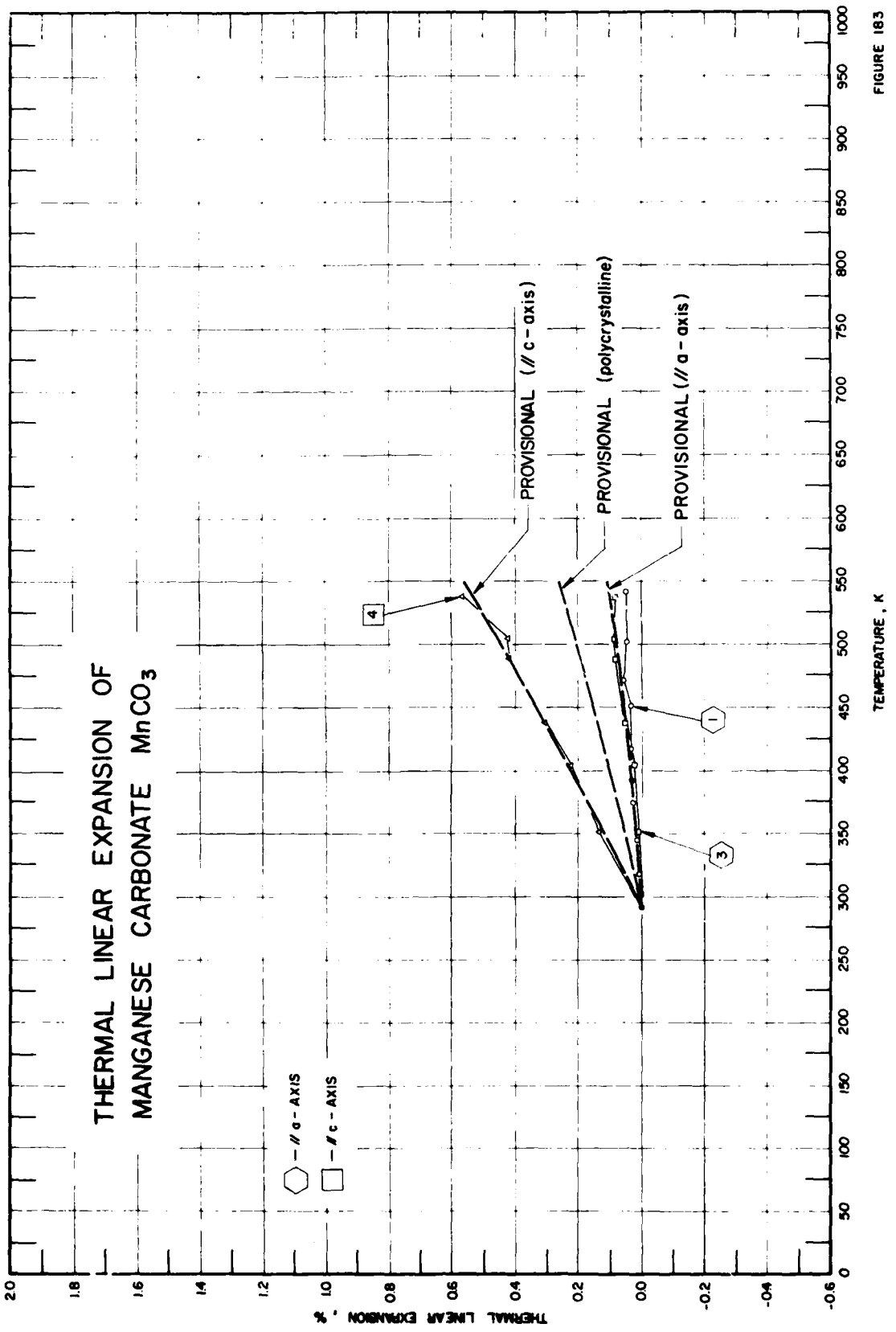

THERMAL LINEAR EXPANSION OF
MANGANESE CARBONATE $MnCO_3$
PROVISIONAL (// c - axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// a - axis)
// a - AXIS
// c - AXIS
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 183

SPECIFICATION TABLE 183. THERMAL LINEAR EXPANSION OF MANGANESE CARBONATE $MnCO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	531	Moreau, R.	1967	X	293-543		Pure, anhydrous specimen; prepared in aqueous solution from metal salt and $NaHCO_3$ solution; expansion measured using $CuK\alpha$ or $CoK\alpha$ radiation along a-axis; lattice parameter reported at 293.2 K is 4.766 kX.
2	531	Moreau, R.	1967	X	293-543		The above specimen; expansion measured along c-axis; lattice parameter reported at 293.2 K is 15.636 kX.
3	718	Rao, K.V.K. and Murthy, K.S.	1970	X	303-538		Transparent natural single crystals of rhombohedral shape supplied by Dr. R. Stevenson, Director, Magnetic Laboratory, Quebec, Canada; single crystals were made into powder, and specimen prepared by pasting powder to thin pyrex rod using Quickfix; lattice parameter measured along a-axis; 4.7719 Å reported at 303 K; 4.7718 Å at 293 K determined by graphical extrapolation; data on coefficient of linear expansion also reported.
4	718	Rao, K.V.K. and Murthy, K.S.	1970	X	303-538		The above specimen; lattice parameter measured along c-axis; 15.6443 Å reported at 353 K; 15.6425 Å at 293 K determined by graphical extrapolation; data on coefficient of linear expansion also reported.

DATA TABLE 183. THERMAL LINEAR EXPANSION OF MANGANESE CARBONATE $MnCO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
293	0.000
318	0.002
345	0.017
375	0.023
393	0.029
417	0.029
453	0.034
473	0.059
503	0.046
543	0.048

CURVE 2

T	$\Delta L/L_0$
293	0.000
318	0.185
345	0.313
375	0.492
393	0.569
417	0.761
453	1.030
473	1.138
503	1.311
543	1.484

CURVE 3

T	$\Delta L/L_0$
303	0.001
351	0.011
405	0.024
438	0.055
488	0.081
505	0.091
538	0.087

CURVE 4

T	$\Delta L/L_0$
303	0.011*
351	0.137
405	0.223
438	0.310
488	0.423
505	0.426
538	0.570

* Not shown in figure.

SPECIFICATION TABLE 184. THERMAL LINEAR EXPANSION OF NICKEL CARBONATE $NiCO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	531	Moreau, R.	1967	X	291-515		Pure, anhydrous specimen; prepared in aqueous solution from metal salt and $NaHCO_3$ solution; expansion measured along a-axis; lattice parameter reported at 291.2 K is 4.591 kX; 4.591 kX at 293.2 K determined by graphical interpolation.
2*	531	Moreau, R.	1967	X	291-515		The above specimen; expansion measured along c-axis; lattice parameter reported at 291.2 K is 14.693 kX; 14.694 kX at 293.2 K determined by graphical interpolation.

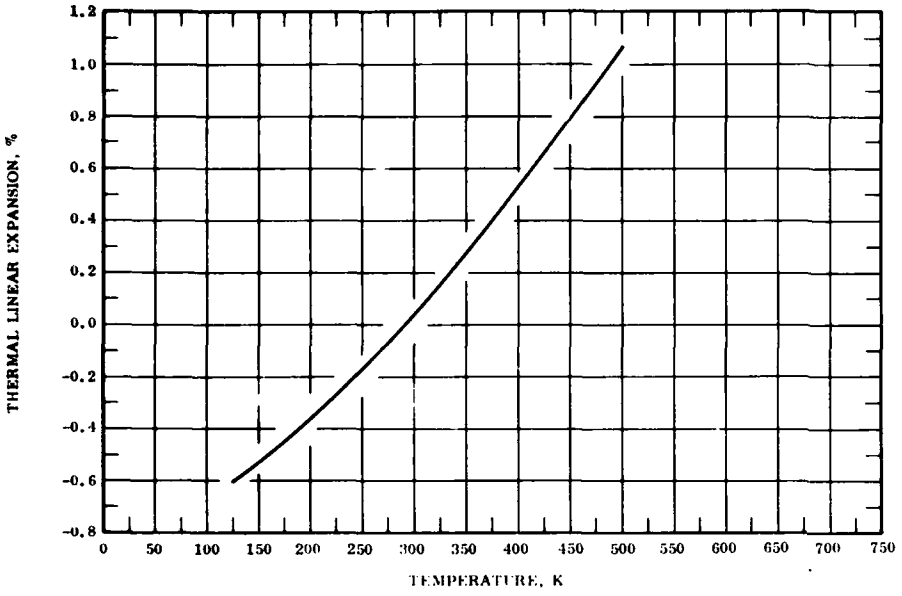
DATA TABLE 184. THERMAL LINEAR EXPANSION OF NICKEL CARBONATE $NiCO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
291.2	0.000
369.2	0.043
393.2	0.087
438.2	0.109
493.2	0.131
515.2	0.174
CURVE 2*	
291.2	-0.007
369.2	0.278
393.2	0.448
438.2	0.557
493.2	0.810
515.2	0.816

* No figure given.

FIGURE AND TABLE NO. 185R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SODIUM CHLORATE $NaClO_3$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, $10^{-6}\ K^{-1}$]

T	$\Delta L/L_0$	α
125	-0.609	31.0
150	-0.535	32.3
175	-0.455	34.0
200	-0.369	35.5
250	-0.180	39.5
293	0.000	43.0
350	0.265	48.4
400	0.515	52.3
450	0.790	56.1
500	1.078	59.8

REMARKS

The recommended values are based on the data for crystal samples and are considered accurate to within ±3%. The values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.890 + 1.617 \times 10^{-3}\ T + 5.159 \times 10^{-6}\ T^2 - 1.065 \times 10^{-9}\ T^3$$

The tabulated values for the coefficient of thermal expansion are primarily based on the experimental data and are considered accurate to about ±5%.

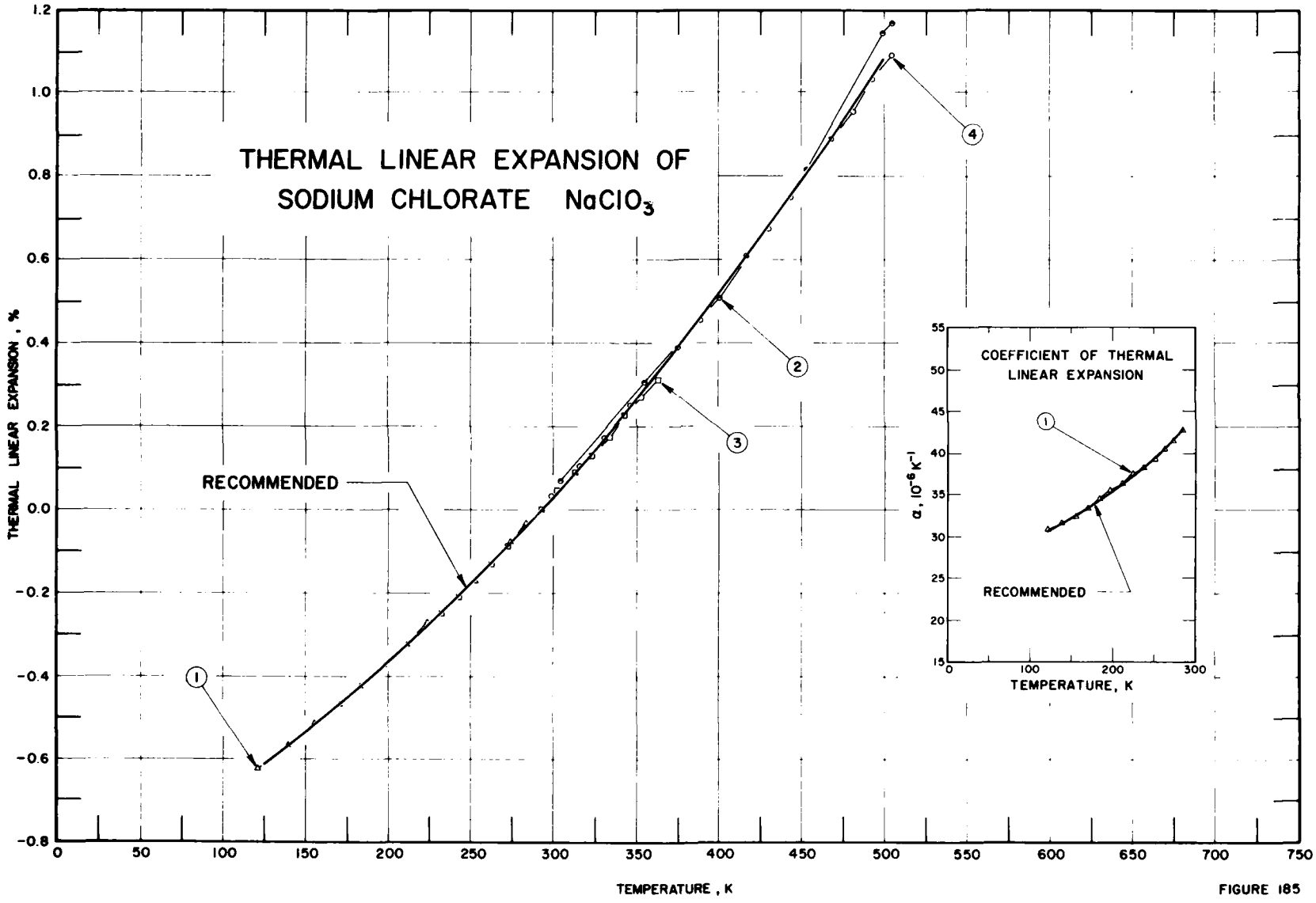

THERMAL LINEAR EXPANSION OF
SODIUM CHLORATE NaClO3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED
1
2
3
4
COEFFICIENT OF THERMAL
LINEAR EXPANSION
α, 10⁻⁶ K⁻¹
RECOMMENDED
TEMPERATURE, K

FIGURE 185

SPECIFICATION TABLE 185. THERMAL LINEAR EXPANSION OF SODIUM CHLORATE $NaClO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	967	Ganesan, S.	1959	I	121-285		Crystal grown from solution; crystalline pyramid cut to 0.459 cm high used as specimen.
2	971	Deshpande, V.T. and Mudholker, V.M.	1960	X	304-505		Lattice parameter 6.5770 Å reported at 304 K.
3	968	Mason, W.P.	1946		233-363		Crystal of sodium chlorate grown from saturated water solution by slowly reducing temperature and depositing salt on a prepared seed; zero-point correction 0.018%.
4	969	Sharma, S.S.	1950	I	299-505		Crystal cut from large transparent crystal, ground right pyramid, 0.3865 cm long; zero-point correction 0.0302%.

DATA TABLE 185. THERMAL LINEAR EXPANSION OF SODIUM CHLORATE $NaClO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1‡		CURVE 2		CURVE 3 (cont.)		CURVE 4		CURVE 4 (cont.)	
121.9	-0.622	304	0.068	263	-0.132	299.4	0.0302	481.1	0.9579
139.7	-0.566	305	0.074*	273	-0.089	315.4	0.1021	493.1	1.0289
155.6	-0.516	355.7	0.306	283	-0.045*	331.0	0.1738	505.0	1.0999
170.0	-0.468	400.7	0.509	293	0.000	346.3	0.2454		
183.8	-0.421	453	0.815	303	0.044	361.1	0.3169*		
197.8	-0.372	500	1.141	313	0.087	375.6	0.3884		
211.4	-0.324	505	1.165	323	0.129	389.6	0.4597		
224.8	-0.274			333	0.175	403.4	0.5310*		
238.0	-0.224*	CURVE 3		343	0.221	417.0	0.6023		
251.0	-0.174			353	0.268	430.3	0.6735		
262.8	-0.127*	233	-0.248	363	0.313	443.4	0.7446		
274.5	-0.079	243	-0.211			456.3	0.8157*		
284.6	-0.036	253	-0.173*			468.8	0.8868		

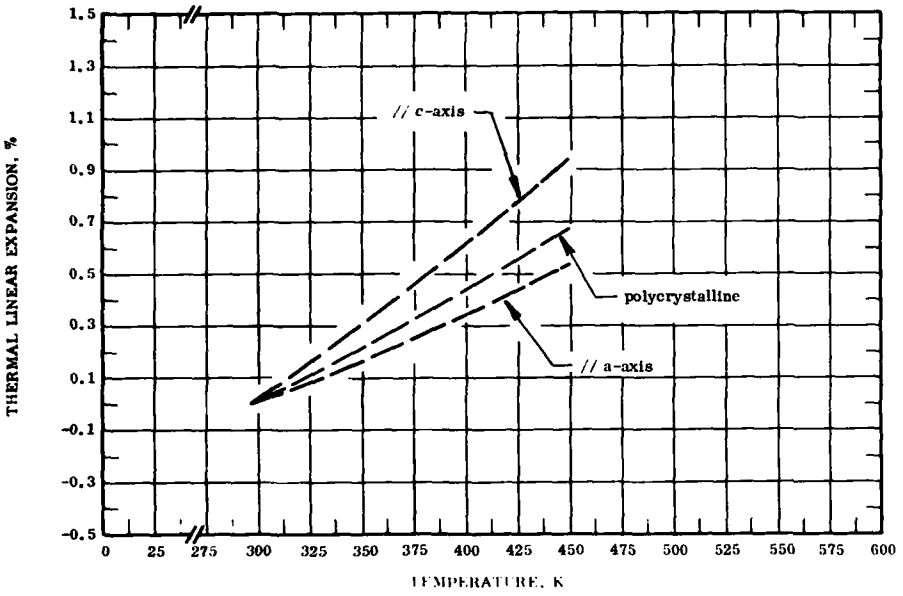
DATA TABLE 185. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM CHLORATE $NaClO_3$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
121.9	30.98
139.7	31.64
155.6	32.33
170.0	33.43
183.8	34.59
197.8	35.42
211.4	36.28
224.8	37.42
238.0	38.15
251.0	39.14
262.8	40.48
274.5	41.61
284.6	42.81

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 186R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF SODIUM IODATE $NaIO_4$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	37
325	0.171	0.092	0.118	38
350	0.309	0.169	0.216	40
375	0.450	0.252	0.318	42
400	0.600	0.339	0.426	45
425	0.760	0.432	0.541	48
450	0.940	0.530	0.667	52

REMARKS

The provisional values for the axial thermal expansion are based on the selected experimental data (Curves 3 and 4). The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ±10% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -2.763 + 1.668 \times 10^{-2}\ T - 3.590 \times 10^{-5}\ T^2 + 3.802 \times 10^{-8}\ T^3$

// a-axis: $\Delta L/L_0 = -0.472 + 5.415 \times 10^{-4}\ T + 3.486 \times 10^{-6}\ T^2 + 5.795 \times 10^{-10}\ T^3$

polycrystalline: $\Delta L/L_0 = -1.563 + 8.621 \times 10^{-3}\ T - 1.698 \times 10^{-5}\ T^2 + 1.963 \times 10^{-8}\ T^3$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equations and are considered accurate to about ±10%.

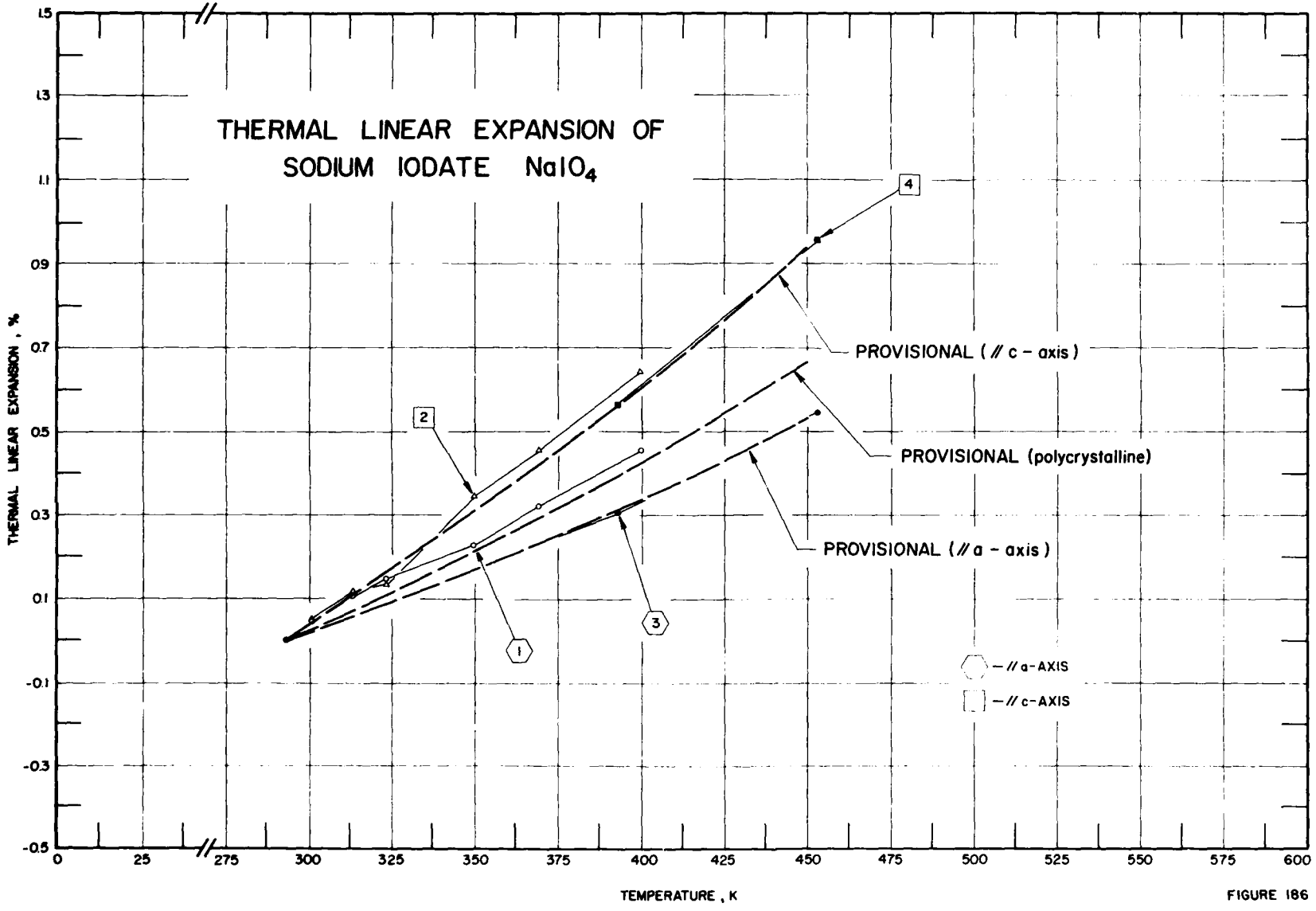

THERMAL LINEAR EXPANSION OF
SODIUM IODATE $NaIO_4$
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.5
1.3
1.1
0.9
0.7
0.5
0.3
0.1
-0.1
-0.3
-0.5
0
25
275
300
325
350
375
400
425
450
475
500
525
550
575
600
1
2
3
4
PROVISIONAL (// c - axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// a - axis)
— // a-AXIS
— // c-AXIS

FIGURE 186

SPECIFICATION TABLE 186. THERMAL LINEAR EXPANSION OF SODIUM IODATE $NaIO_4$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	972	Deshpande, V.T., Suryanarayana, S.V., and Pawar, R.R.	1968	X	301-400		Expansion measured along a-axis; 5.3387 Å reported at 301.7 K; coefficient of linear thermal expansion also reported.
2	972	Deshpande, V.T., et al.	1968	X	301-400		Expansion measured along c-axis; 11.9556 Å reported at 301.7 K; coefficient of linear thermal expansion also reported.
3	973	Bayer, G.	1972	X	293-453		Commercially available specimen from Merck; lattice parameter measured along a-axis; 5.3354 Å reported at 293 K.
4	973	Bayer, G.	1972	X	293-453		The above specimen; lattice parameter measured along c-axis; 11.9454 Å reported at 293 K.

DATA TABLE 186. THERMAL LINEAR EXPANSION OF SODIUM IODATE $NaIO_4$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3		CURVE 4	
301.7	0.045	301.7	0.051	293	0.000	293	0.000*
313.2	0.105	313.2	0.119	393	0.304	393	0.561
323.2	0.148	323.2	0.138	453	0.547	453	0.958
350.2	0.231	350.2	0.347				
369.2	0.321	369.2	0.458				
400.2	0.458	400.2	0.646				

DATA TABLE 186. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM IODATE $NaIO_4$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α
CURVE 1*		CURVE 1 (cont.)*		CURVE 2*		CURVE 2 (cont.)*	
303	38.5	363	42.1	303	54.9	363	65.4
313	38.9	373	43.4	313	57.0	373	66.8
323	39.3	383	44.2	323	58.8	383	68.6
333	40.1	393	44.2	333	60.8	393	70.0
343	40.7			343	62.2		
353	40.7			353	63.8		

* Not shown in figure.

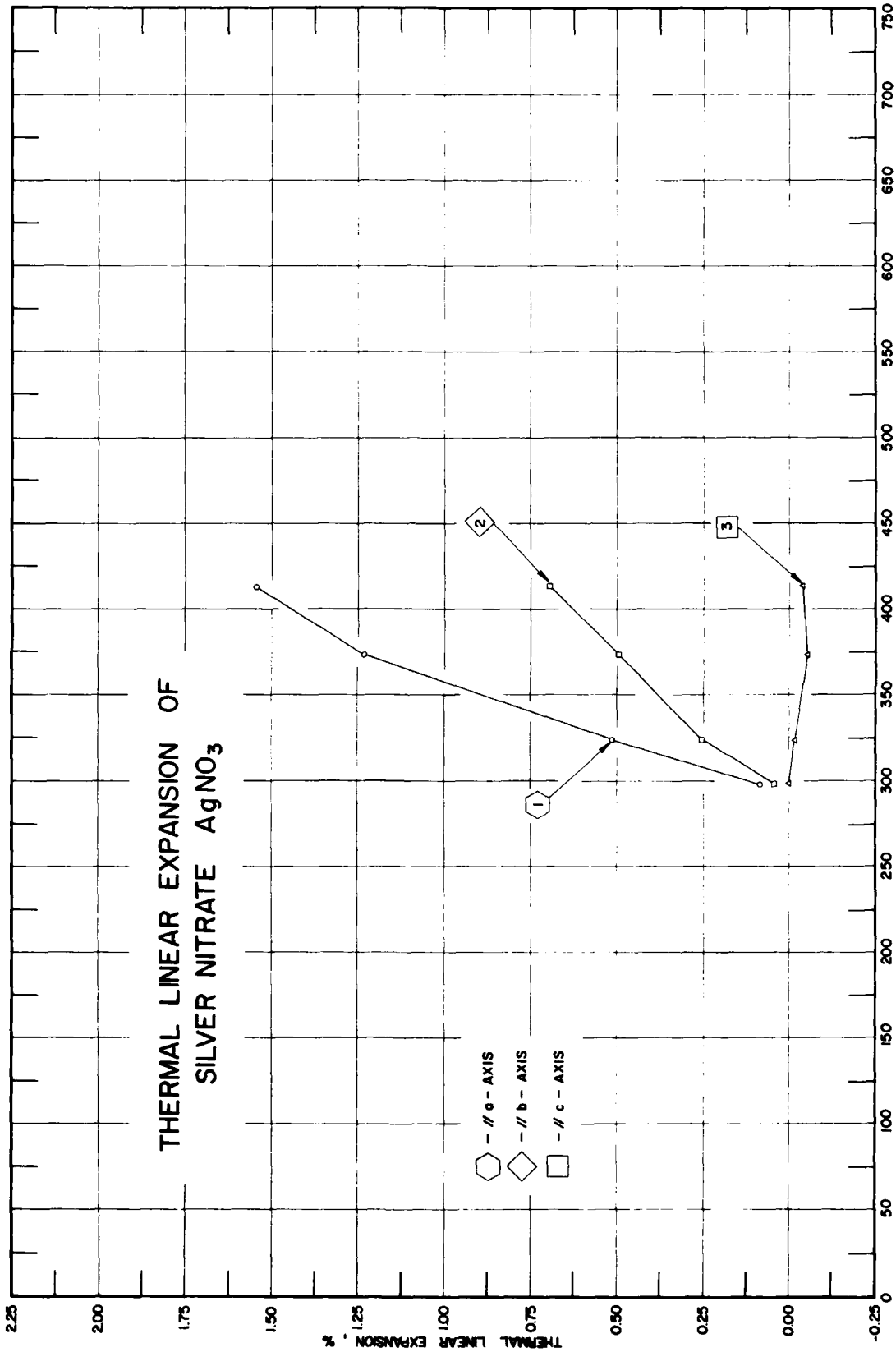

THERMAL LINEAR EXPANSION OF
SILVER NITRATE $AgNO_3$
// a - AXIS
// b - AXIS
// c - AXIS
1
2
3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750

FIGURE 187

SPECIFICATION TABLE 187. THERMAL LINEAR EXPANSION OF SILVER NITRATE $AgNO_3$

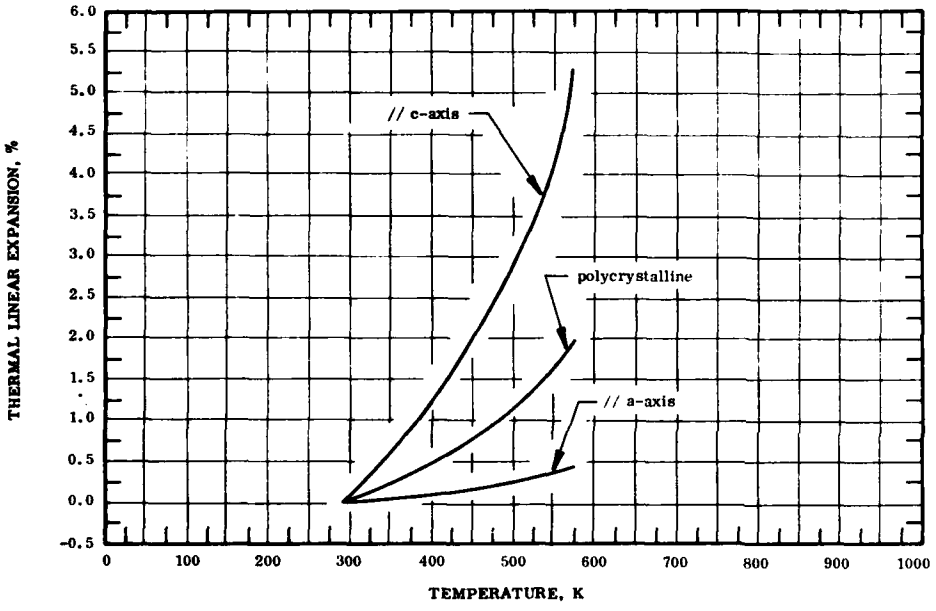
Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	302	Levin, E.M.	1969	X	298-413		Powder specimen; orthorhombic form; expansion measured along a-axis; lattice parameter reported at 298.2 K is 6.995 Å; 6.989 Å at 293.2 K determined by graphical extrapolation.
2	302	Levin, E.M.	1969	X	298-413		The above specimen; expansion measured along b-axis; lattice parameter reported at 298.2 K is 7.330 Å; 7.327 Å at 293.2 K determined by graphical extrapolation.
3	302	Levin, E.M.	1969	X	298-413		The above specimen; expansion measured along c-axis; lattice parameter reported at 298.2 K is 10.122 Å; 10.122 Å at 293.2 K determined by graphical extrapolation.
4	302	Levin, E.M.	1969	X	298-448		Powder specimen; rhombohedral form; metastable below 428 K; lattice parameter reported at 298.2 K is 6.287 Å; 6.283 Å at 293.2 K determined by graphical extrapolation.

DATA TABLE 187. THERMAL LINEAR EXPANSION OF SILVER NITRATE $AgNO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		**CURVE 4**	
298	0.086	298	0.064
323	0.515	373	1.114
373	1.231	433	1.719
413	1.545	448	2.180
CURVE 2			
298	0.041		
323	0.257		
373	0.491		
413	0.696		
CURVE 3			
298	0.000		
323	-0.020		
373	-0.059		
413	-0.039		

FIGURE AND TABLE NO. 188R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SODIUM NITRATE $NaNO_3$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// c-axis	// a-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	40
325	0.325	0.012	0.137	43
350	0.600	0.032	0.245	44
375	0.903	0.058	0.358	47
400	1.235	0.090	0.481	52
425	1.580	0.127	0.620	58
450	1.980	0.170	0.775	67
475	2.415	0.214	0.950	77
500	2.917	0.263	1.160	89
525	3.465	0.315	1.360	103
550	4.158	0.365	1.675	127
575	5.250	0.422	1.995	

REMARKS

The recommended values for the axial thermal expansion are based on the data for pure samples. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ±5% and are represented approximately by the following equations:

// c-axis: $\Delta L/L_0 = -5.451 + 3.372 \times 10^{-2} T - 7.705 \times 10^{-5} T^2 + 8.615 \times 10^{-8} T^3$ (293-550 K)

// a-axis: $\Delta L/L_0 = 0.646 - 5.282 \times 10^{-3} T + 1.252 \times 10^{-5} T^2 - 6.972 \times 10^{-9} T^3$ (293-550 K)

polycrystalline: $\Delta L/L_0 = -2.787 + 1.873 \times 10^{-2} T - 4.533 \times 10^{-5} T^2 + 4.731 \times 10^{-8} T^3$ (293-550 K)

The tabulated values for the coefficient of thermal expansion are primarily based on the experimental data and are considered accurate to about ±7%.

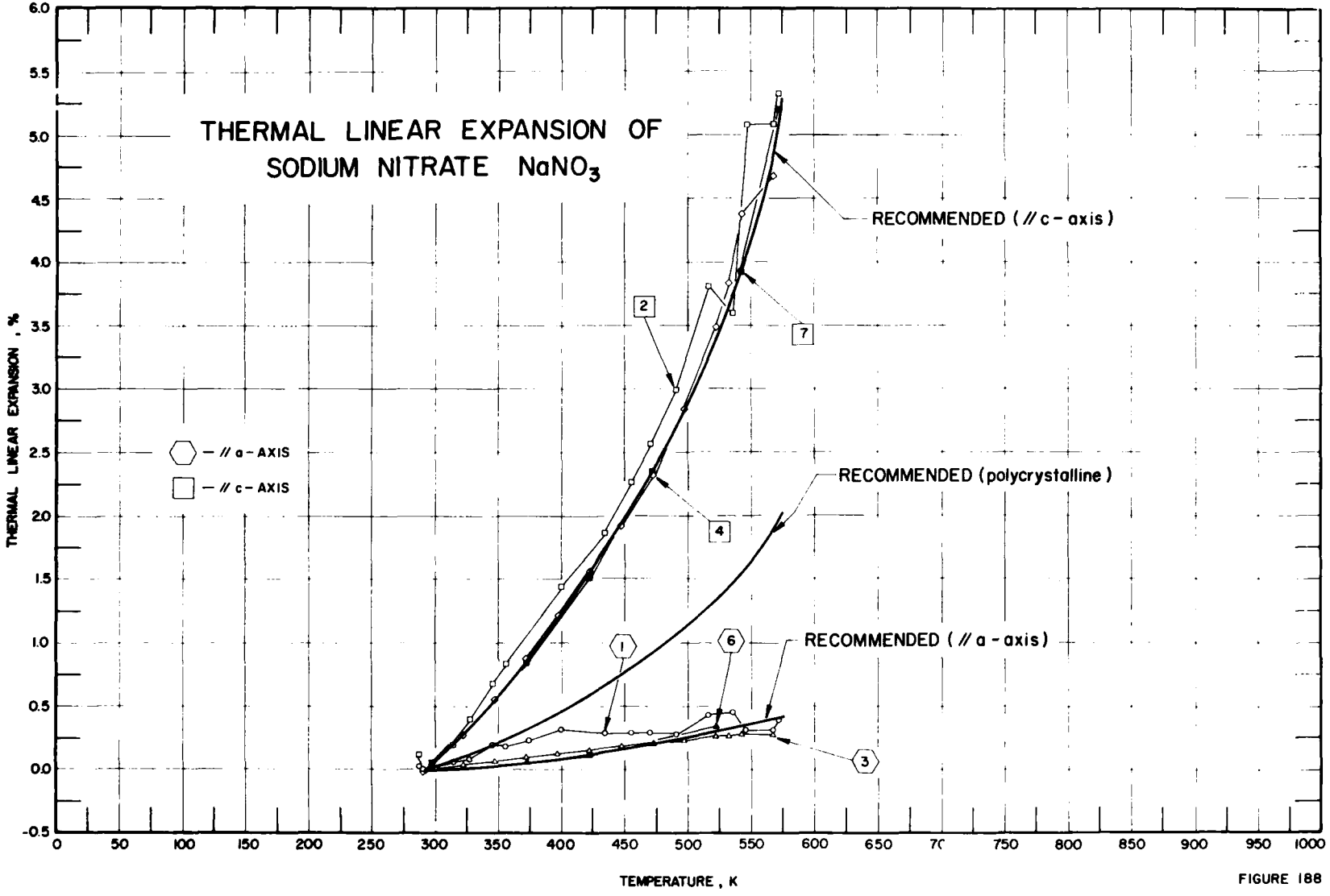

THERMAL LINEAR EXPANSION OF
SODIUM NITRATE $NaNO_3$
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
— // a - AXIS
— // c - AXIS
RECOMMENDED (// c - axis)
RECOMMENDED (polycrystalline)
RECOMMENDED (// a - axis)
1
2
3
4
6
7
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0
50
100
150
200
250
300
350
400
450
500
550
600
650
750
800
850
900
950
1000

FIGURE 188

SPECIFICATION TABLE 188. THERMAL LINEAR EXPANSION OF SODIUM NITRATE $NaNO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	295	Hsu, Y.T.	1967	X	289-573		Reagent grade powder of hexagonal crystal; placed in 0.3 mm diameter capillary; expansion measured along a-axis; lattice parameter reported at 289.2 K is 5.066 Å; 5.067 Å at 293.2 K determined by graphical interpolation.
2	295	Hsu, Y.T.	1967	X	289-573		The above specimen; expansion measured along c-axis; lattice parameter reported at 289.2 K is 16.815 Å; 16.834 Å at 293.2 K determined by graphical interpolation.
3	306	Austin, J.B. and Pierce, R.H.H.	1933	I	291-568		Specimen crystallized three times; expansion measured along a-axis; zero-point correction of -0.002% determined by graphical interpolation.
4	306	Austin, J.B. and Pierce, R.H.H.	1933	I	291-568		Similar to the above specimen; expansion measured along c-axis; zero-point correction of -0.02% determined by graphical interpolation.
5*	306	Austin, J.B. and Pierce, R.H.H.	1933	I	291-568		Similar to the above specimen; expansion measured perpendicular to $10\bar{1}1$ face; zero-point correction of -0.02% determined by graphical interpolation.
6	722	Krishna Rao, K.V. and Murthy, K.S.	1970	X	298-573		Specimen from crystals obtained from solution in water of an analar grade sample; expansion measured along a-axis; 5.0694 Å reported at 298 K; 5.0694 Å at 293 K determined by graphical extrapolation; data on coefficient of linear expansion also reported.
7	722	Krishna Rao, K.V. and Murthy, K.S.	1970	X	298-573		The above specimen; expansion measured along c-axis; 16.8200 Å reported at 298 K; 16.8111 Å at 293 K determined by graphical extrapolation; data on coefficient of linear expansion also reported.

* Not shown in figure.

DATA TABLE 188. THERMAL LINEAR EXPANSION OF SODIUM NITRATE $NaNO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
289	0.019
291	0.000
315	0.059
328	0.079
346	0.197
357	0.178
375	0.237
401	0.316
435	0.296
456	0.296
471	0.296
492	0.276
517	0.434
537	0.454
547	0.316
569	0.316
573	0.395
CURVE 2	
289	0.113
291	0.000
315	0.196
328	0.392
346	0.677
357	0.832
375	-4.79
401	1.44
435	1.86
456	2.26
471	2.57
492	2.99
517	3.81
537	3.59
547	5.09
569	5.09
573	5.34
CURVE 3	
291	-0.002
323	0.033
348	0.060
373	0.091
398	0.120
423	0.148
448	0.175
473	0.201
498	0.228
523	0.253
533	0.263
543	0.273
568	0.278
CURVE 4	
291	-0.02
323	0.26
348	0.55
CURVE 4 (cont.)	
373	0.87
398	1.21
423	1.56
448	1.92
473	2.32
498	2.84
523	3.49
533	3.84
543	4.38
568	4.68
CURVE 5*	
291	-0.02
323	0.23
348	0.42
373	0.61
398	0.81
423	1.01
CURVE 5 (cont.)*	
448	1.22
473	1.43
498	1.75
523	2.22
533	2.45
543	2.51
568	2.88
CURVE 6	
298	0.000
373	0.063
423	0.118
473	0.191*
523	0.349
573	0.387*
CURVE 7	
298	0.053
373	0.849
423	1.503
473	2.343
523	3.921
573	5.214

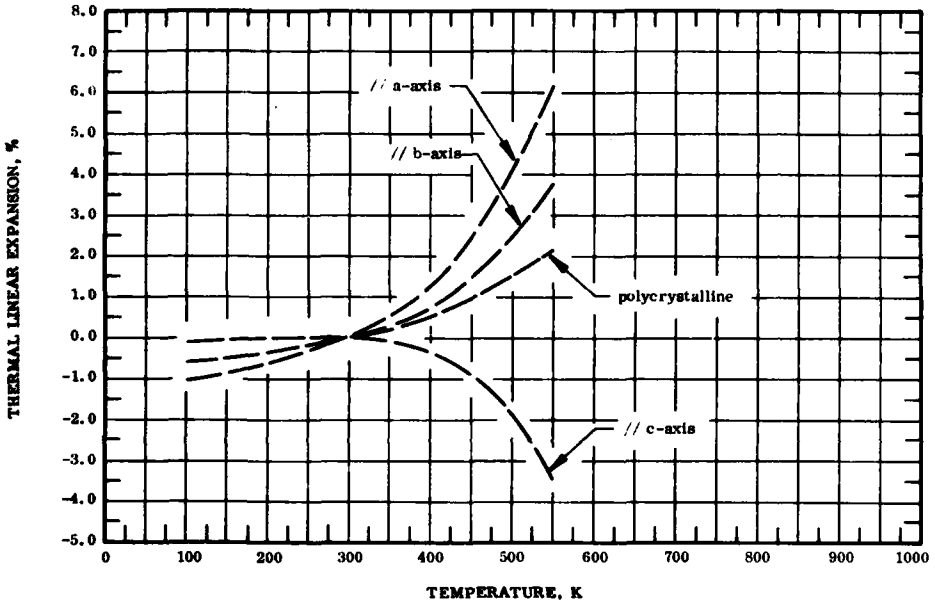
DATA TABLE 188. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM NITRATE $NaNO_3$

[Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\ K^{-1}$]

T	α
CURVE 6*	
323	8.33
363	9.27
403	11.64
443	14.10
483	18.44
523	22.29
583	25.89
CURVE 7*	
323	104.01
363	117.68
403	132.82
443	163.44
483	208.94
CURVE 7 (cont.)*	
523	264.67
583	375.17

* Not shown in figure.

FIGURE AND TABLE NO. 189R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF SODIUM NITRITE $NaNO_2$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// b-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
100	-1.06	-0.60	-0.10	-0.59	22
150	-0.82	-0.48	-0.07	-0.46	25
200	-0.57	-0.32	-0.03	-0.31	29
250	-0.28	-0.17	-0.01	-0.15	33
293	0.00	0.00	0.00	0.00	38
350	0.52	0.27	-0.09	0.24	49
400	1.32	0.75	-0.35	0.55	70
450	2.51	1.48	-0.90	0.99	80
500	4.11	2.48	-1.86	1.57	
550	6.15	3.75	-3.45	2.13	

REMARKS

The provisional values for the axial thermal expansion are based on the data for single crystal samples. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ±10% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = 2.33 - 1.73 \times 10^{-2} T + 1.79 \times 10^{-5} T^2 + 4.75 \times 10^{-8} T^3$ (293-550 K)

// b-axis: $\Delta L/L_0 = 2.09 - 1.43 \times 10^{-2} T + 1.62 \times 10^{-5} T^2 + 2.77 \times 10^{-8} T^3$ (293-550 K)

// c-axis: $\Delta L/L_0 = 3.96 - 4.16 \times 10^{-2} T + 1.45 \times 10^{-4} T^2 - 1.70 \times 10^{-7} T^3$ (293-550 K)

polycrystalline: $\Delta L/L_0 = -3.79 + 2.94 \times 10^{-2} T - 8.32 \times 10^{-5} T^2 + 9.19 \times 10^{-8} T^3$ (293-550 K)

The tabulated values for the coefficient of thermal expansion are based on the selected experimental data and are considered accurate to about ±15%.

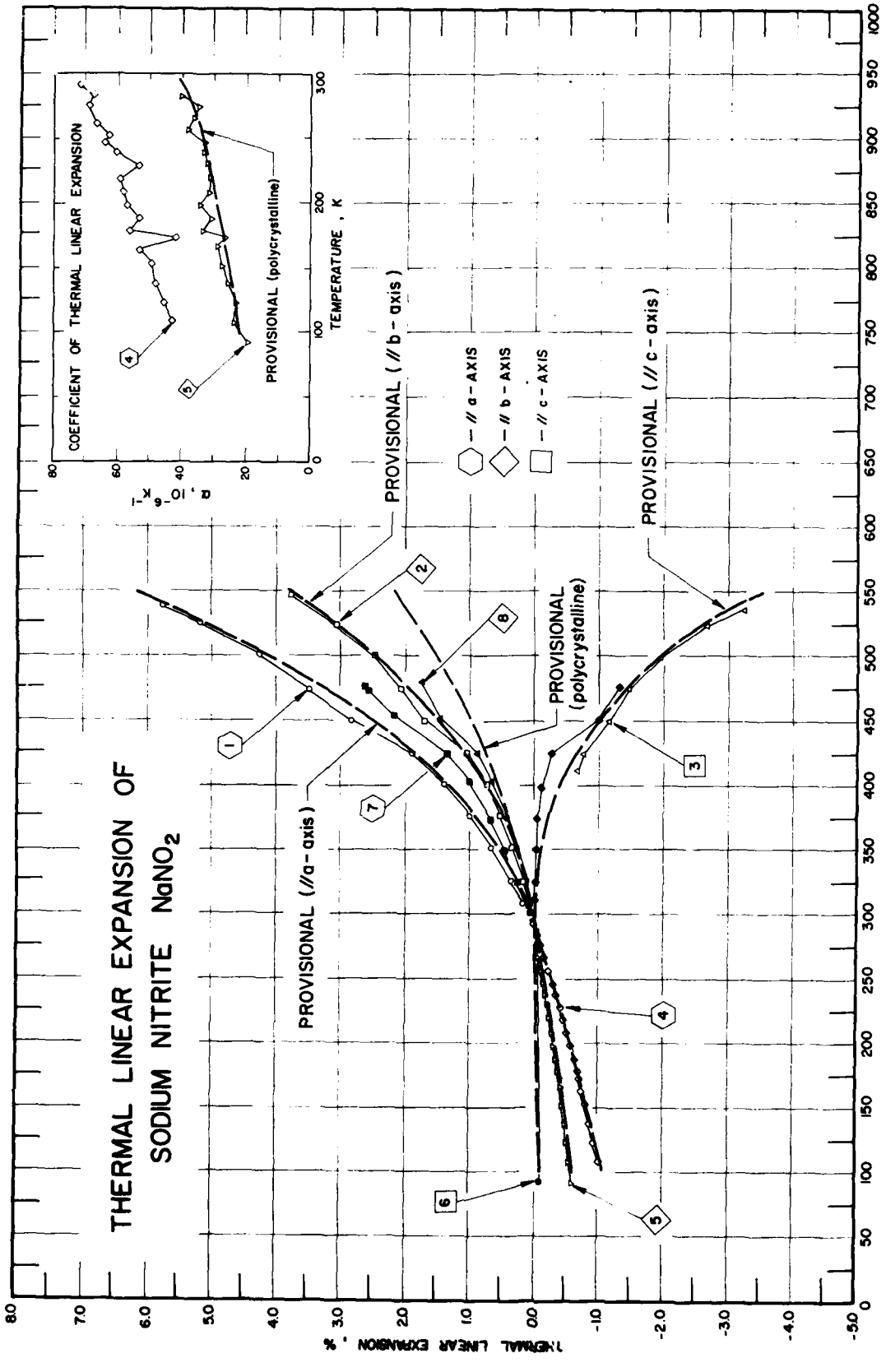

THERMAL LINEAR EXPANSION OF SODIUM NITRITE $NaNO_2$
PROVISIONAL (// a - axis)
PROVISIONAL (// b - axis)
PROVISIONAL (// c - axis)
PROVISIONAL (polycrystalline)
— // a - AXIS
— // b - AXIS
— // c - AXIS
COEFFICIENT OF THERMAL LINEAR EXPANSION
PROVISIONAL (polycrystalline)
TEMPERATURE , K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K

FIGURE 189

SPECIFICATION TABLE 189. THERMAL LINEAR EXPANSION OF SODIUM NITRITE $NaNO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	303	Maruyama, N. and Sawada, S.	1965	D	309-538		Specimen 2.5 mm diameter, 12 mm long, cylinder parallel to [100] axis of crystal; prepared by cooling from a melt, then cut and dried several days above the Curie temperature.
2	303	Maruyama, N. and Sawada, S.	1965	D	307-546		Specimen cut from same crystal as above except cylinder parallel to [010] axis.
3	303	Maruyama, N. and Sawada, S.	1965	D	412-537		Specimen cut from same crystal as above except cylinder parallel to [001] axis.
4	304	Gesi, K.	1969	L	109-293		Single crystal grown by means of Kyropoulos method from molten salt of reagent grade; rectangular prism shape specimen of Ca 0.5 x 0.5 x 1.5 cm of which largest sides parallel to crystallographic axes; heating rate 1 C per min; expansion measured along [100] direction.
5	304	Gesi, K.	1969	L	92-284		The above specimen; expansion measured along [010] direction.
6	304	Gesi, K	1969	L	93, 293		The above specimen; expansion measured along [001] direction.
7	305	Nomura, N.	1961	L	293-477		Single crystal, orthorhombic structure; dimensions of crystal a = 0.848 cm, b = 0.997 cm, c = 1.040 cm; expansion measured along a-axis; coefficient of thermal linear expansion are also reported.
8	305	Nomura, N.	1961	L	293-480		The above specimen; expansion measured along b-axis; coefficient of thermal linear expansion are also reported.
9	305	Nomura, N.	1961	L	293-476		The above specimen; expansion measured along c-axis; coefficient of thermal linear expansion are also reported.

DATA TABLE 189. THERMAL LINEAR EXPANSION OF SODIUM NITRITE $NaNO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 2‡		CURVE 2 (cont.)‡		CURVE 2 (cont.)‡		CURVE 3 (cont.)‡	
309	0.172	427	1.955*	307	0.076	420	0.957*	535	3.338*	509	-2.159*
312	0.204*	430	2.049*	310	0.092*	423	1.005*	539	3.482*	512	-2.241*
316	0.247*	432	2.121*	312	0.103*	425	1.039	541	3.559*	515	-2.327*
319	0.280*	434	2.204*	315	0.119*	427	1.076*	543	3.644*	517	-2.388*
323	0.325*	437	2.350*	318	0.136*	430	1.134*	546	3.779	519	-2.452*
326	0.359	439	2.462*	320	0.147*	432	1.176*			522	-2.555*
329	0.393*	442	2.606*	322	0.158*	435	1.247*	CURVE 3		525	-2.668
331	0.416*	445	2.704*	325	0.175	437	1.308*			527	-2.752*
334	0.451*	447	2.759*	328	0.193*	439	1.420*	412	-0.686	530	-2.884*
336	0.474*	450	2.840	330	0.204*	442	1.570*	414	-0.697*	532	-2.984*
338	0.498*	452	2.894*	333	0.222*	445	1.628*	417	-0.717*	534	-3.095*
342	0.546*	454	2.947*	334	0.228*	447	1.658*	420	-0.738*	537	-3.272
343	0.558*	457	3.026*	337	0.246*	450	1.701	422	-0.754*		
346	0.595*	459	3.080*	340	0.264*	452	1.728*	425	-0.781	CURVE 4‡	
349	0.632*	462	3.161*	342	0.277*	455	1.769*	428	-0.811*		
351	0.657	464	3.215*	344	0.289*	457	1.796*	430	-0.833*	109	-1.028
354	0.695*	466	3.268*	347	0.308	460	1.838*	433	-0.875*	123	-0.965
356	0.721*	469	3.349*	349	0.320*	462	1.866*	436	-0.931*	138	-0.898
358	0.747*	472	3.430*	352	0.340	465	1.909*	438	-0.982*	153	-0.828
360	0.773*	474	3.484	354	0.352*	467	1.939*	441	-1.046*	164	-0.772
363	0.813*	477	3.566*	357	0.372*	470	1.983*	442	-1.059*	174	-0.724
366	0.853*	479	3.621*	360	0.392*	472	2.012*	445	-1.095*	179	-0.700
369	0.893*	481	3.676*	362	0.405*	474	2.042	447	-1.119*	188	-0.650
371	0.920*	484	3.759*	365	0.425*	479	2.116*	450	-1.153	198	-0.595
373	0.948*	486	3.815*	367	0.439*	482	2.161*	452	-1.177*	209	-0.531
376	0.991	489	3.900*	370	0.460*	484	2.192*	455	-1.214*	219	-0.472
378	1.019*	492	3.988*	373	0.481*	486	2.224*	459	-1.266*	229	-0.416
381	1.063*	494	4.048*	373	0.481*	489	2.273*	462	-1.306*	238	-0.364
384	1.107*	496	4.110*	376	0.503	491	2.307*	464	-1.333*	247	-0.308
386	1.137*	498	4.174*	379	0.526*	494	2.358*	467	-1.374*	257	-0.245
389	1.183*	501	4.271	381	0.541*	496	2.393*	470	-1.416*	267	-0.180
391	1.214*	504	4.368*	384	0.566*	499	2.448*	472	-1.445*	276	-0.119
393	1.246*	506	4.435*	387	0.591*	501	2.485	475	-1.489	285	-0.057
396	1.296*	509	4.536*	389	0.607*	504	2.543*	478	-1.534*	293	0.000
399	1.346*	511	4.605*	391	0.625*	506	2.583*	480	-1.565*		
402	1.398	514	4.711*	393	0.643*	509	2.645*	483	-1.615*	CURVE 5‡	
403	1.416*	516	4.784*	396	0.671*	511	2.689*	485	-1.649*		
405	1.452*	519	4.899*	398	0.690*	514	2.757*	487	-1.685*	92	-0.611
408	1.509*	521	4.978*	401	0.720	516	2.804*	490	-1.740*	108	-0.577
410	1.548*	524	5.098*	403	0.741*	518	2.852*	492	-1.778*	124	-0.538
413	1.610*	526	5.182	406	0.774*	521	2.926*	495	-1.837*	138	-0.504
415	1.652*	529	5.317*	408	0.797*	524	3.004*	497	-1.879*	152	-0.467
418	1.721*	531	5.411*	411	0.833*	526	3.058	500	-1.944	166	-0.428
420	1.769*	534	5.558*	413	0.859*	529	3.144*	502	-1.989*	174	-0.406
422	1.819*	536	5.660*	416	0.899*	531	3.205*	505	-2.058*	178	-0.394
425	1.898	538	5.767	418	0.926*	533	3.270*	507	-2.107*	188	-0.361

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 189. THERMAL LINEAR EXPANSION OF SODIUM NITRITE $NaNO_2$ (continued)

T	$\Delta L/L_0$
CURVE 5 (cont.)‡	
199	-0.325
209	-0.293
220	-0.258
231	-0.223
239	-0.197
248	-0.167
257	-0.135
267	-0.097
276	-0.065
284	-0.035
CURVE 6	
93	-0.12
293	0.00*
CURVE 7	
293	0.000*
296	0.011*
301	0.044
306	0.081*
311	0.110*
316	0.150*
320	0.185*
325	0.227
330	0.260*
334	0.304*
340	0.339*
345	0.394*
350	0.443
355	0.486*
359	0.526*
364	0.580*
369	0.620*
374	0.668
379	0.717*
384	0.774*
389	0.828*
394	0.878*
398	0.930*
403	0.997
408	1.058*
414	1.154*
419	1.241*
425	1.343
429	1.468*
432	1.543*

T	$\Delta L/L_0$
CURVE 7 (cont.)	
433	1.607*
434	1.668*
435	1.711*
436	1.743*
437	1.782*
437	1.822*
438	1.857*
439	1.878*
440	1.901*
441	1.931*
443	1.959*
444	1.989*
446	2.021*
448	2.073*
454	2.161
456	2.203*
458	2.247*
462	2.301*
464	2.353*
466	2.400*
469	2.460*
474	2.555
477	2.624
CURVE 8	
293	0.000*
295	0.000
301	0.018*
307	0.041*
311	0.060*
317	0.086*
321	0.103*
325	0.125
331	0.142*
335	0.169*
340	0.196*
346	0.220*
351	0.253
356	0.283*
361	0.318*
365	0.344*
370	0.362*
375	0.407
379	0.437*
384	0.477*
390	0.517*
395	0.555*

T	$\Delta L/L_0$
CURVE 8 (cont.)	
399	0.602*
404	0.646
409	0.703*
415	0.759*
420	0.819*
425	0.876
426	0.887*
428	0.928*
431	0.980*
432	1.031*
433	1.065*
434	1.098*
435	1.122*
435	1.139*
436	1.157*
436	1.176*
437	1.196*
437	1.211*
437	1.239*
437	1.280*
438	1.287*
438	1.290*
438	1.298*
439	1.304*
439	1.310*
439	1.318*
440	1.338*
442	1.356*
442	1.367*
443	1.377*
444	1.385*
445	1.400*
447	1.417*
449	1.437*
452	1.469
455	1.496*
457	1.525*
461	1.552*
466	1.600*
470	1.651*
475	1.690*
480	1.744
CURVE 9	
293	0.000*
295	0.000*
301	-0.008*

T	$\Delta L/L_0$
CURVE 9 (cont.)‡	
306	-0.008*
311	-0.008
316	-0.008*
320	-0.013*
325	-0.013
330	-0.013*
335	-0.019*
340	-0.022*
344	-0.022*
350	-0.031
355	-0.031*
365	-0.039*
370	-0.039*
374	-0.050
384	-0.069*
389	-0.082*
394	-0.090*
399	-0.103
404	-0.129*
409	-0.144*
414	-0.185*
419	-0.225*
425	-0.281
430	-0.370*
431	-0.423*
434	-0.543*
436	-0.636*
437	-0.698*
438	-0.764*
439	-0.789*
441	-0.818*
442	-0.850*
444	-0.888*
446	-0.927*
449	-0.970*
451	-1.001
454	-1.048*
458	-1.094*
461	-1.136*
465	-1.196*
470	-1.251*
476	-1.313

* Not shown in figure.

DATA TABLE 189. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM NITRITE $NaNO_2$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α	T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 2*,‡		CURVE 2 (cont.)*,‡		CURVE 2 (cont.)*,‡		CURVE 3 (cont.)*,‡	
309	107	427	296	307	53.8	420	159.7	535	353.4	509	-268.8
312	108	430	334	310	54.2	423	165.6	539	366.3	512	-279.3
316	108	432	382	312	54.7	425	175.7	541	406.5	515	-294.1
319	111	434	450	315	55.4	427	186.9	543	436.7	517	-313.5
323	113	437	521	318	55.4	430	201.2	546	467.3	519	-335.6
326	113	439	599	320	56.1	432	217.4			522	-347.2
329	114	442	365	322	57.2	435	256.4	CURVE 3*,‡		525	-408.2
331	116	445	285	325	57.1	437	359.7			527	-425.5
334	116	447	269	328	58.1	439	757.6	412	-53.5	530	-458.7
335	116	450	270	330	59.0	442	239.2	414	-61.6	532	-543.5
338	120	452	269	333	59.0	445	152.4	417	-69.2	534	-565.0
342	121	454	262	334	59.5	447	147.7	420	-73.9	537	-613.5
343	122	457	268	337	60.4	450	136.6	422	-82.5		
346	122	459	268	340	61.0	452	134.6	425	-96.2	CURVE 4‡	
349	125	462	272	342	61.7	455	136.6	428	-104.2		
351	127	464	265	344	62.5	457	138.5	430	-119.9	109	42.9
354	127	466	271	347	63.5	460	138.5	433	-157.0	123	45.7
356	130	469	268	349	62.9	462	141.0	436	-217.4	138	44.0
358	130	472	271	352	64.0	465	148.6	438	-293.3	153	49.3
360	132	474	271	354	65.0	467	144.3	441	-134.3	164	53.2
363	133	477	275	357	66.3	470	148.4	442	-124.4	174	42.0
366	135	479	277	360	65.8	472	148.6	445	-117.2	179	56.5
369	135	481	272	362	67.0	474	148.1	447	-114.8	188	53.5
371	137	484	280	365	67.7	479	148.1	450	-116.7	198	57.1
373	141	486	277	367	69.4	482	152.2	452	-122.2	209	58.1
376	143	489	288	370	70.4	484	157.0	455	-126.1	219	59.9
378	143	492	300	373	70.4	486	163.4	459	-131.4	229	53.8
381	146	494	307	373	71.5	489	164.5	462	-137.2	238	60.6
384	147	496	312	376	74.4	491	170.4	464	-133.0	247	64.1
386	152	498	325	379	76.2	494	172.7	467	-139.1	257	62.9
389	155	501	319	381	79.4	496	178.3	470	-142.5	267	66.7
391	159	504	333	384	83.0	499	184.2	472	-147.1	276	69.0
393	163	506	333	387	83.0	501	191.2	475	-148.1	285	67.6
396	166	509	339	389	85.3	504	196.5	478	-149.3	293	71.9
399	169	511	350	391	89.1	506	202.8	480	-161.8		
402	176	514	358	393	93.1	509	211.9	483	-168.6	CURVE 5‡	
403	182	516	373	396	93.5	511	221.2	485	-175.4		
405	185	519	394	398	98.2	514	232.6	487	-180.8	92	19.3
408	191	521	394	401	103.5	516	235.3	490	-185.2	108	24.0
410	201	524	407	403	106.4	518	244.5	492	-193.1	124	23.6
413	210	526	437	406	112.5	521	250.0	495	-205.8	138	25.4
415	219	529	459	408	116.6	524	268.8	497	-211.0	152	27.3
418	237	531	478	411	125.2	526	276.2	500	-223.1	166	29.0
420	244	534	503	413	129.4	529	294.1	502	-227.3	174	26.4
422	256	536	518	416	136.2	531	318.5	505	-233.6	178	33.9
425	271	538	559	418	141.0	533	330.0	507	-250.0	188	31.0

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 189. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM NITRITE $NaNO_2$ (continued)

T	α
CURVE 5 (cont.)‡	
199	34.1
209	31.4
220	31.4
231	32.2
239	33.8
248	33.1
257	38.2
267	36.6
276	35.1
284	40.3
CURVE 7*	
293	69
295	73
301	78
307	79
312	79
316	79
321	84
326	84
331	84
335	93
341	93
351	93
356	94
362	98
371	105
379	108
384	116
390	119
394	129
400	138
405	152
414	166
419	179
425	197
430	231
434	295
434	314
435	358
436	377
436	412
437	515
437	536
437	569
437	1206
437	1180

T	α
CURVE 7 (cont.)*	
438	529
438	475
439	357
440	304
440	209
442	216
445	220
447	194
449	217
454	191
456	194
459	194
464	201
467	201
469	201
475	197
480	202
CURVE 8*	
293	40
295	43
302	43
308	43
312	43
317	43
321	50
326	50
330	50
335	52
341	57
351	57
356	57
362	59
370	63
380	70
385	71
390	77
395	80
400	93
405	96
410	106
415	118
420	129
426	148
430	191
432	219
433	275

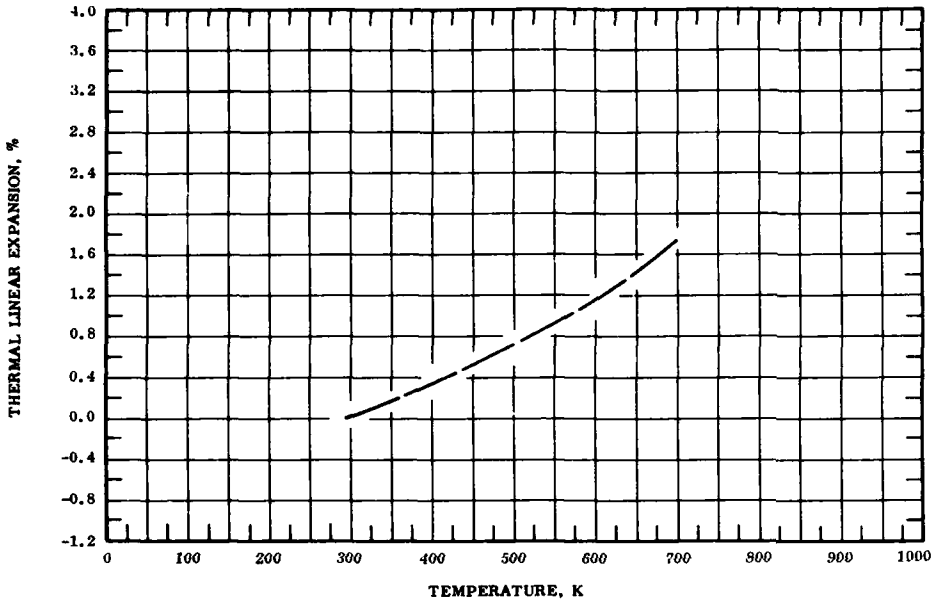
T	α
CURVE 8 (cont.)*	
435	358
436	377
436	412
437	515
437	536
437	569
437	1206
437	1180
438	529
438	449
438	357
438	323
438	266
438	222
438	199
439	162
440	120
442	127
443	110
445	128
447	110
452	104
455	95
458	105
463	105
466	101
468	107
470	108
476	101
481	105
CURVE 9*	
293	0.0
295	0.0
302	0.0
308	0.0
312	0.0
316	0.0
320	0.0
326	0.0
331	0.0
335	0.0
341	0.0
345	0.0
350	0.0
356	0.0
361	0.0

T	α
CURVE 9 (cont.)*	
365	0.0
371	-1.0
379	-5.0
384	-12.0
390	-11.0
395	-19.0
400	-22.0
404	-34.0
410	-51.0
415	-64.0
420	-73.0
426	-111.0
428	-125.0
431	-174.0
433	-212.0
435	-262.0
436	-339.0
436	-415.0
437	-575.0
438	-345.0
438	-227.0
439	-144.0
440	-128.0
441	-116.0
443	-123.0
444	-143.0
446	-135.0
451	-156.0
455	-156.0
457	-156.0
459	-156.0
462	-140.0
466	-156.0
470	-164.0
475	-155.0
481	-162.0

* Not shown in figure

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 190R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF STRONTIUM NITRATE $Sr(NO_3)_2$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	32
350	0.185	33
400	0.354	35
450	0.535	37
500	0.727	40
550	0.937	44
600	1.167	48
650	1.421	53
700	1.701	59

REMARKS

The provisional values are considered accurate to within ± 10% and are represented approximately by the following equation:

$$\Delta L/L_0 = -1.001 + 4.018 \times 10^{-3} T - 3.376 \times 10^{-6} T^2 + 4.500 \times 10^{-9} T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ± 10%.

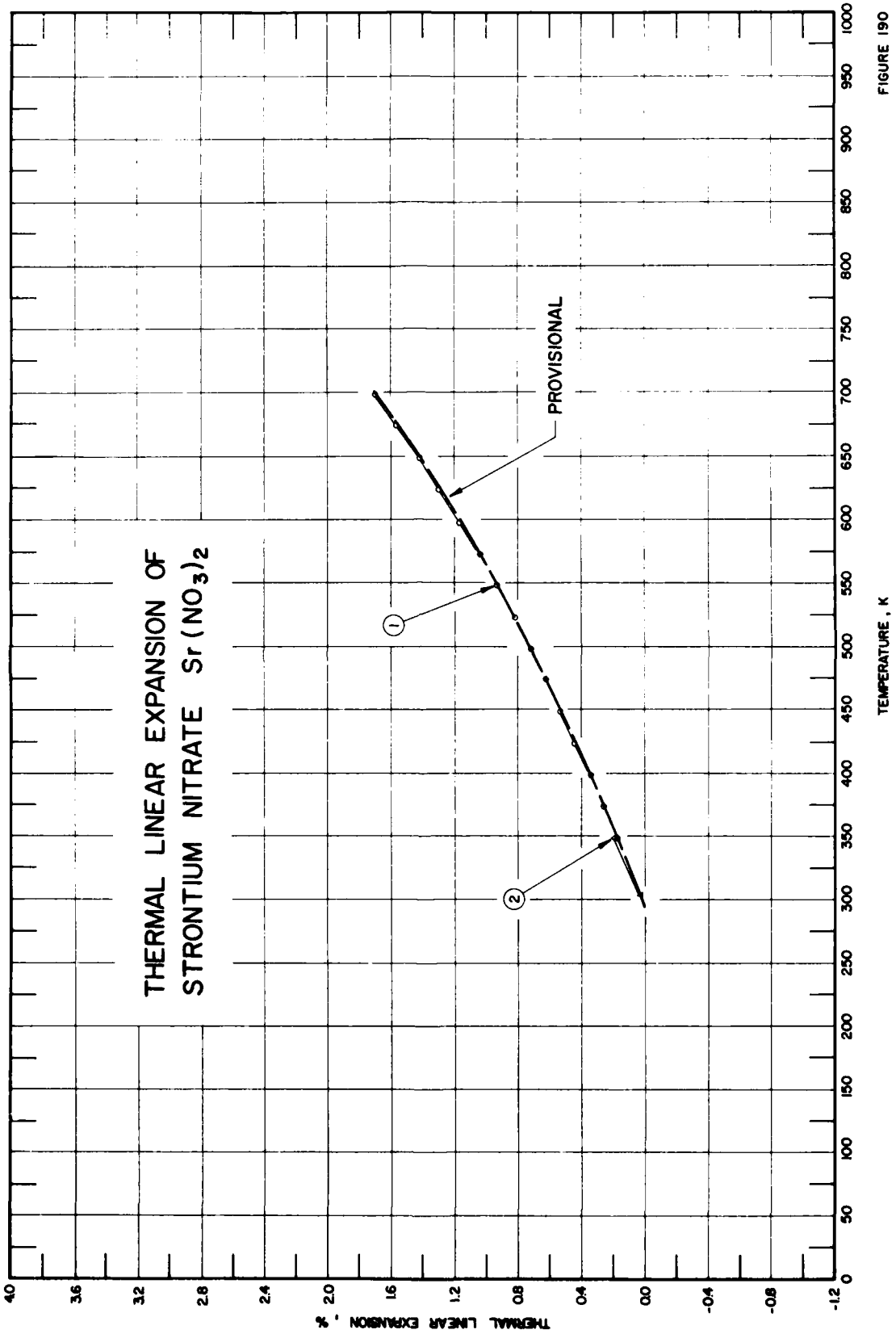

THERMAL LINEAR EXPANSION OF
STRONTIUM NITRATE Sr(NO3)2
PROVISIONAL
1
2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 190

SPECIFICATION TABLE 190. THERMAL LINEAR EXPANSION OF STRONTIUM NITRATE $Sr(NO_3)_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	296	Srinivasan, R.	1955	I	348-798		Transparent crystal of 4 to 5 mm height; prepared by slow evaporation from saturated solution of salt, ground to pyramid form; heating rate less than 1 C per min.
2	632	Bridgman, P.W.	1932		303, 348		Powder material obtained from Eimer and Amend; expansion measured at atmospheric pressure.

DATA TABLE 190. THERMAL LINEAR EXPANSION OF STRONTIUM NITRATE $Sr(NO_3)_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2	
348	0.176	303	0.032
373	0.261	348	0.177
398	0.349		
423	0.442		
448	0.533		
473	0.626		
498	0.726		
523	0.823		
548	0.933		
573	1.042		
598	1.165		
623	1.294		
648	1.427		
673	1.558		
698	1.709		
723	1.935		
748	2.175		
773	2.314		
798	2.353		

SPECIFICATION TABLE 191. THERMAL LINEAR EXPANSION OF MISCELLANEOUS NITRATES AND NITRITES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	295	Hsu, Y. T.	1967	X	293-318	NH_4NO_3	Ammonium nitrate; reagent grade powder of Phase IV orthorhombic crystal, placed in 0.3 mm diameter capillary; transfer to tetragonal phase II at 45 ± 3 C; expansion measured along a-axis; lattice parameter reported at 291.2-293.2 K is 4.913 Å.
2*	295	Hsu, Y. T.	1967	X	293-318	NH_4NO_3	Ammonium nitrate; the above specimen; expansion measured along b-axis; lattice parameter reported at 291.2-293.2 K is 5.426 Å.
3*	295	Hsu, Y. T.	1967	X	293-318	NH_4NO_3	Ammonium nitrate; the above specimen; expansion measured along c-axis; lattice parameter reported at 291.2-293.2 K is 5.782 Å.
4*	295	Hsu, Y. T.	1967	X	339-397	NH_4NO_3	Ammonium nitrate; reagent grade powder of Phase II tetragonal crystal; transfer to simple cubic phase at 124 ± 3 C; expansion measured along a-axis; lattice parameter reported at 318.2 K is 5.677 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
5*	295	Hsu, Y. T.	1967	X	339-397	NH_4NO_3	Ammonium nitrate; the above specimen; expansion measured along c-axis; lattice parameter reported at 318.2 K is 4.902 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
6*	296	Srinivasan, R.	1955	I	348-498	$Ba(NO_3)_2$	Barium nitrate; transparent crystal of 4 to 5 mm high grown by slow evaporation from saturated solution of salt, ground to pyramid form; heating rate less than 1 C per min.
7*	297	Gladkii, V.V. and Zheludev, I.S.	1967	L	88-247	$Ba(NO_2)_2 \cdot H_2O$	Barium nitrite hydrate; single crystal specimen; expansion measured perpendicular to the axis of 6th order (axis z).
8*	297	Gladkii, V.V. and Zheludev, I.S.	1967	L	87-289	$Ba(NO_2)_2 \cdot H_2O$	Barium nitrite hydrate; the above specimen; expansion measured along the axis of 6th order.
9*	300	Bottomley, M.J., Perry, G.S., and Ubbelohde, A.R.	1964	X	224-298	$C_{24}NO_3$, x HNO_3	Graphite nitrate; crystal compound; specimen prepared by direct immersion of 0.1 x 5 x 10 mm stress-annealed graphite in mixture of 50% HNO_3 (s.g. 1.52 by weight) with 50% N_2O_5 prepared by distillation from HNO_3 and P_2O_5; spacing reported at 293 K in 7.84 Å; expansion measured along c-axis; first sequence intercalation.
10*	300	Bottomley, M.J., et al.	1964	X	222-297	$C_{24}NO_3$, x HNO_3	Graphite nitrate; crystal compound specimen prepared by direct immersion of 0.1 x 5 x 10 mm stress-annealed graphite in HNO_3 (s.g. 1.52); spacing reported at 293 K in 11.14 Å; expansion measured along c-axis; second sequence intercalation.
11*	300	Bottomley, M.J., et al.	1964	X	219-299	$C_{24}NO_3$, x HNO_3	Graphite nitrate; crystal compound specimen obtained by direct immersion of 0.1 x 5 x 10 mm stress-annealed graphite for 12 hr in mixture containing 40% by volume of HNO_3 (s.g. 1.42) with 60% by volume of HNO_3 (s.g. 1.52); spacing reported at 293 K is 14.49 Å; expansion measured c-axis; third sequence intercalation.
12*	296	Srinivasan, R.	1955	I	348-448	$Pb(NO_3)_2$	Lead nitrate; transparent crystal of 4 to 5 mm height; prepared by slow evaporation from saturated solution of salt, ground to pyramid form, heating rate less than 1 C per min.
13*	301	Salhota, P.P., Subbarao, J.C., and Venkateswarlu, P.	1968	L	355-551	$RbNO_3$	Rubidium nitrate; 99.8 pure specimen; obtained from Penn Rare Metals, Inc.; cast molten into rods 0.4 mm diameter, 1.5 cm long; structure changed from trigonal to cubic to rhombohedral and to cubic as temperature increased from room temperature to melting point.

* No figure given.

DATA TABLE 191. THERMAL LINEAR EXPANSION OF MISCELLANEOUS NITRATES AND NITRITES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
307	-0.651
318	-0.244
CURVE 2*	
293	0.000
307	0.369
318	0.756
CURVE 3*	
293	0.000
307	0.484
318	0.761
CURVE 4*, †	
318	0.000
339	0.211
355	0.458
380	0.511
397	0.511
CURVE 5*, †	
318	0.000
339	0.082
355	0.082
380	0.489
397	0.489
CURVE 6*	
348	0.101
373	0.153
398	0.209
423	0.270
448	0.335
473	0.403
498	0.475

T	$\Delta L/L_0$
CURVE 7*, ‡	
88	-0.258
108	-0.247
125	-0.234
143	-0.217
160	-0.198
178	-0.176
196	-0.151
214	-0.124
233	-0.095
247	-0.073
CURVE 8*, ‡	
87	-1.1751
105	-1.1010
123	-1.0290
140	-0.9518
171	-0.7968
185	-0.7201
199	-0.6387
250	-0.3128
260	-0.2434
279	-0.1055
289	-0.0301
CURVE 9*	
224	1.083
231	1.022
245	0.884
249	0.852
256	0.742
260	0.288
268	0.210
270	0.190
273	0.143
278	0.122
282	0.083
287	0.027
296	-0.014
298	-0.039

T	$\Delta L/L_0$
CURVE 10*	
222	0.885
229	0.861
237	0.792
238	0.781
246	0.648
247	0.713
248	0.708
249	0.648
251	0.619
252	0.538
253	0.346
257	0.274
258	0.247
261	0.243
262	0.210
266	0.175
275	0.103
276	0.113
277	0.131
293	0.000
294	0.025
295	0.032
297	-0.025
CURVE 11*	
219	0.795
237	0.662
242	0.617
245	0.612
248	0.549
249	0.565
252	0.499
254	0.253
259	0.201
260	0.201
266	0.148
275	0.097
280	0.064
286	0.047
289	0.016
299	-0.023

T	$\Delta L/L_0$
CURVE 12*	
348	0.181
373	0.267
398	0.355
423	0.447
448	0.539
CURVE 13*	
355	0.29
366	0.40
375	0.49
385	0.58
394	0.66
404	0.77
414	0.89
424	1.00
428	1.12
430	1.27
433	1.58
434	1.93
438	2.06
449	2.20
458	2.34
468	2.52
478	2.70
483	2.77
485	3.09
487	3.67
488	4.33
492	5.08
493	5.81
495	6.38
498	6.58
500	6.74
505	6.86
520	6.99
530	7.12
537	7.20
541	7.28
543	7.50
548	7.67
551	7.74

* No figure given.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 191. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS NITRATES AND NITRITES

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 7*,‡	
88	5.1
106	6.5
125	8.3
143	10.4
160	11.8
178	13.0
196	14.9
214	14.9
233	15.6
247	16.0
CURVE 8*,‡	
87	37.1
105	40.9
123	43.8
141	47.0
171	53.0
185	56.5
199	59.8
250	68.0
260	70.8
279	74.4
289	76.3

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 192. THERMAL LINEAR EXPANSION OF LEAD PHOSPHATES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	310	Argyle, J. F. and Hummel, F.A.	1960	L	293-833	$Pb(PO_3)_2$ ($PbO \cdot P_2O_5$)	Lead metaphosphate; 61.12 PbO and 38.88 P_2O_5; specimen prepared from lead carbonate and diammonium hydrogen phosphate hand-mixed with acetone for 15 to 20 min, air-dried overnight, calcined at 373 K for 4 hr, fired at 823 K for 6 hr, cooled, ground, remixed, pressed into pellets (1 cm diameter by 1 cm long) at 1000 psi, fired at 823 K for 12 hr so that complete reaction occured, ground, mixed with Carbowax solution, forced through 20-mesh sieve, pressed into 1 x 1 x 10 cm bar at 1000 psi, and sintered to a relatively dense condition; original length 110.3 mm; heating rate 120 C per hr.
2*	310	Argyle, J. F. and Hummel, F.A.	1960	L	293-1000	$Pb_2P_2O_7$ ($2PbO \cdot P_2O_5$)	Lead pyrophosphate; 75.89 PbO and 24.11 P_2O_5; specimen prepared from c.p. lead carbonate and diammonium hydrogen phosphate lead-mixed with acetone for 15 to 20 min, air-dried overnight, calcined at 473 K for 4 hr, fired at 1073 K for 6 hr, cooled, ground, remixed, pressed into pellets (1 cm diameter by 1 cm long) at 1000 psi, fired at 1073 for 24 hr so that complete reaction occured, ground, mixed with carbowax solution, forced through 20-mesh sieve, pressed into 1 x 1 x 10 cm bar at 1000 psi, and sintered to a relatively dense condition; original length 83.0 mm; heating rate 120 C per hr.
3*	310	Argyle, J. F. and Hummel, F.A.	1960	L	293-1130	$Pb_3(PO_4)_2$ ($3PbO \cdot P_2O_5$)	Lead orthophosphate; 82.50 PbO and 17.50 P_2O_5; specimen prepared from c.p. lead carbonate and diammonium hydrogen phosphate hand-mixed with acetone for 15 to 20 min, air-dried overnight, calcined at 473 K for 4 hr, fired at 1 1223 K for 6 hr, cooled, ground, remixed, pressed into pellets (1 cm diameter by 1 cm long) at 1000 psi, fired at 1223 K for 24 hr so that complete reaction occured, ground, mixed with carbowax solution, forced through 20-mesh sieve, pressed into 1 x 1 x 10 cm bar at 1000 psi and sintered to a relatively dense condition; author states that data indicates a reversible inversion; original length 97.6 mm; heating rate 120 C per hr.
4*	310	Argyle, J. F. and Hummel, F.A.	1960	L	293-900	$Pb_3P_4O_{13}$ ($3PbO \cdot 2P_2O_5$)	Lead tetraphosphate; 70.22 PbO and 29.78 P_2O_5; specimen prepared from c.p. lead carbonate and diammonium hydrogen phosphate hand-mixed with acetone for 15 to 20 min, air-dried overnight, calcined at 473 K for 4 hr, fired at 923 K for 6 hr, cooled, ground, remixed, pressed into pellets (1 cm diameter by 1 cm long) at 1000 psi, fired at 923 K for 24 hr so that complete reaction occured, ground, mixed with carbowax solution, forced through 20-mesh sieve, pressed into 1 x 1 x 10 cm bar at 1000 psi, and sintered to a relatively dense condition; original length 110.4 mm; heating rate 120 C per hr.
5*	310	Argyle, J. F. and Hummel, F.A.	1960	L	293-1114	$Pb_5P_4O_{15}$ ($5PbO\ 2P_2O_5$)	Lead phosphate; 79.72 PbO and 20.28 P_2O_5; specimen prepared from c.p. lead carbonate and diammonium hydrogen phosphate hand-mixed with acetone for 15 to 20 min, air-dried overnight, calcined at 373 K for hr, fired 1173 K for 6 hr, cooled, ground, remixed, pressed into pellets (1 cm diameter by 1 cm long) at 1000 psi, fired at 1173 K for 24 hr so that complete reaction occured, ground, mixed with carbowax solution, forced through 20-mesh sieve, pressed into 10 x 1 x 1 cm bar at 1000 psi and sintered to a relatively dense condition, author states that data indicates an inversion or discontinuity; original length 98.5 mm; measured with heating rate 120 C per hr.

* No figure given.

SPECIFICATION TABLE 192. THERMAL LINEAR EXPANSION OF LEAD PHOSPHATES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
6*	310	Argyle, J. F. and Hummel, F. A.	1960	L	293-1041	$Pb_8P_2O_{13}$ ($8PbO \cdot P_2O_5$)	Lead phosphate; 92.15 PbO and 7.85 P_2O_5; specimen prepared from c.p. lead carbonate and diammonium hydrogen phosphate hand-mixed with acetone for 15 to 20 min, air-dried overnight, calcined at 473 K for 4 hr, fired at 1073 K for 6 hr, cooled, ground, remixed, pressed into pellets (1 cm diameter by 1 cm long) at 1000 psi, fired at 1073 K for 24 hr so that complete reaction occured, ground, mixed with carbowax solution, forced through 20-mesh sieve, pressed into 10 x 1 x 1 cm bar at 1000 psi, and sintered to a relatively dense condition; author states that the data indicates an inversion or discontinuity; original length 98.5 mm; measured with heating rate of 120 C per min.
7*	286	Argyle, J. F. and Hummel, F. A.	1963	L	293-783	$Pb_5GeP_2O_{12}$ ($5PbO \cdot GeO_2 \cdot P_2O_5$) Apatite-type	Lead germanium phosphate; specimen prepared from c.p. chemicals hand mixed with acetone for 15 to 20 min, air dried, heated slowly to 300 C for 4 hr, remixed calcined at 773 K for 24 hr, cooled, remixed, recalcined at 973 K for 24 hr, ground, mixed with carbowax solution, modulized through a 20-mesh sieve, pressed into 1 x 1 x 10 cm bar at 1000 psi, and fired slowly to 783 K for 6 hr; melting temperature 995 C; heating rate 120 C per hr.
8*	310	Argyle, J. F. and Hummel, F. A.	1960	L	293-1145	$Pb_5SiP_2O_{12}$ ($5PbO\ SiO_2\ P_2O_5$)	Lead silicon phosphate; 84.67 PbO, 10.77 P_2O_5, and 4.56 SiO_2; specimen prepared from c.p. lead carbonate, silicic acid, and diammonium hydrogen phosphate hand-mixed with acetone for 15 to 20 min, air-dried overnight, calcined at 473 K for 4 hr, fired to 1223 K for 6 hr, cooled, ground, remixed, fired at 1223 K for 24 hr, ground, mixed with Carbowax solution, forced through 20-mesh sieve, pressed into 10 x 1 x 1 cm bars at 1000 psi, and sintered to a relatively dense condition; original length 97.5 mm; measured with heating rate of 120 C per hr.

* No figure given.

DATA TABLE 192. THERMAL LINEAR EXPANSION OF LEAD PHOSPHATES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
293	0.000
323	0.020
373	0.059
423	0.116
473	0.171
523	0.232
573	0.304
623	0.380
673	0.468
723	0.560
773	0.626
823	0.682
833	0.689

CURVE 2*

T	$\Delta L/L_0$
293	0.000
323	0.013
373	0.049
423	0.093
473	0.144
523	0.203
573	0.261
623	0.334
673	0.401
723	0.482
773	0.552
823	0.625
873	0.689
923	0.718
973	0.729
1000	0.735

CURVE 3*

T	$\Delta L/L_0$
293	0.000
323	-0.007
373	-0.027
423	-0.075
452	-0.134
473	-0.206
523	-0.147
573	-0.086
623	-0.007

CURVE 3 (cont.)*

T	$\Delta L/L_0$
673	0.007
723	0.188
773	0.277
823	0.375
873	0.470
923	0.567
973	0.657
1023	0.759
1073	0.853
1123	0.947
1130	0.959

CURVE 4*

T	$\Delta L/L_0$
293	0.000
323	0.021
373	0.066
423	0.128
473	0.192
523	0.262
573	0.342
623	0.434
673	0.528
723	0.645
773	0.743
823	0.849
873	0.904
900	0.909

CURVE 5*

T	$\Delta L/L_0$
293	0.000
323	0.032
373	0.092
423	0.164
473	0.254
523	0.377
573	0.533
585	0.565
623	0.565
673	0.571
723	0.584
773	0.600
823	0.628

CURVE 5 (cont.)*

T	$\Delta L/L_0$
873	0.670
923	0.732
973	0.801
1023	0.900
1073	1.022
1114	1.090

CURVE 6*

T	$\Delta L/L_0$
293	0.000
323	0.023
373	0.077
423	0.141
445	0.154
473	0.154
523	0.052
544	0.040
573	0.055
623	0.142
673	0.215
723	0.299
773	0.375
823	0.459
873	0.559
923	0.655
973	0.740
1023	0.841
1041	0.880

CURVE 7*

T	$\Delta L/L_0$
293	0.000
298	0.006
309	0.013
321	0.033
336	0.063
363	0.113
399	0.178
433	0.247
467	0.314
504	0.386
539	0.458
576	0.535
612	0.612

CURVE 7 (cont.)*

T	$\Delta L/L_0$
653	0.694
701	0.786
744	0.883
783	0.978

CURVE 8*

T	$\Delta L/L_0$
302	0.000
323	0.065
373	0.150
423	0.230
473	0.308
523	0.419
573	0.524
623	0.613
673	0.719
723	0.837
773	0.950
823	1.056
873	1.148
923	1.258
973	1.372
1023	1.469
1073	1.548
1123	1.603
1145	1.616

* No figure given.

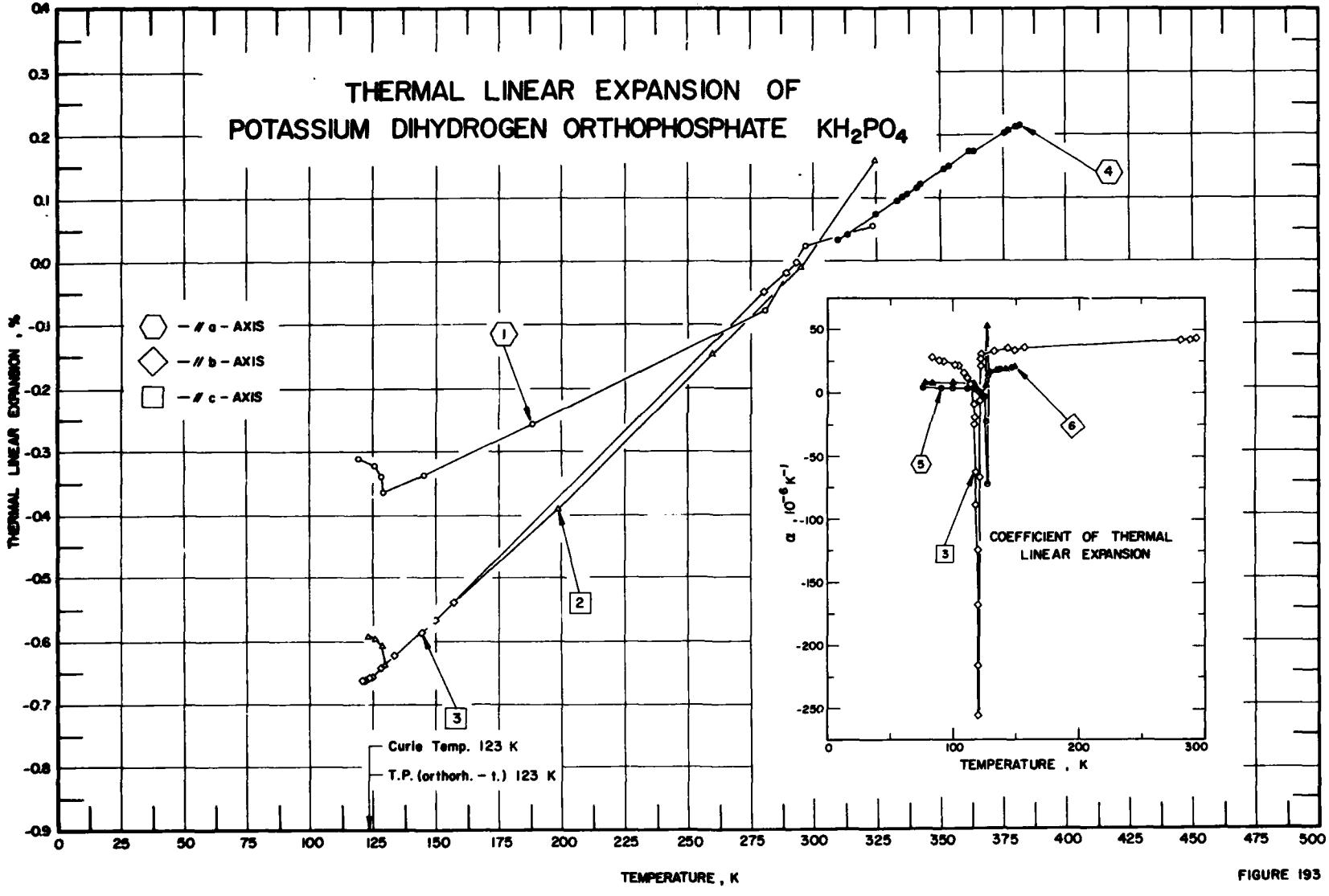

THERMAL LINEAR EXPANSION OF
POTASSIUM DIHYDROGEN ORTHOPHOSPHATE KH_2PO_4
// a - AXIS
// b - AXIS
// c - AXIS
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
Curie Temp. 123 K
T.P. (orthorh. - t.) 123 K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10^{-6} K^{-1}
TEMPERATURE , K

FIGURE 193

SPECIFICATION TABLE 193. THERMAL LINEAR EXPANSION OF POTASSIUM DIHYDROGEN ORTHOPHOSPHATE KH_2PO_4

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	287	Cook, W.R.	1967	I	119-323		Specimen length 7.2 mm; expansion measured as average of a- and b-axes of orthorhombic structure below Curie point 123 K; and a-axis of tetragonal structure above this Curie point; 7.4529 Å of tetragonal structure reported at 298 K; total contractions from 298 K to Curie point 0.378 %; zero-point correction 0.013%.
2	287	Cook, W.R.	1967	I	119-324		Similar to the above specimen; specimen length 4.5 mm; expansion measured along c-axis; 6.9751 Å of tetragonal structure reported at 298 K; total contraction from 298 K to Curie point 0.674%; zero-point correction is 0.034%.
3	739	Smolenko, L.A. Sidnenko, E.V., and Zheluder, I.S.	1967	L	121-293		Dilatometer sensitivity 170 Å, accuracy to 1-3% (10-20° steps) (15-20%) for 0.5-1° steps near T_C; specimen linear dimensions of 1 cm curve along a four-fold axis ($\alpha_{33}=\alpha_3$).
4	740	Poplavko, Yu.M., Rez, I.S., Gorbokon, N.V., and Dimarova, E.N.	1972	O	293-382		Optical-mechanical dilatometer-sensitivity of 10^{-5} mm/division temperature of specimen stabilized over 20-30 min with accuracy of 0.05°, curve for α_1.
5*	882	Krajewski, T.	1969		77-146		Expansion measured along a-axis; this curve is here reported using the first temperature (77 K) as reference temperature at which $\Delta L/L_0 = 0$.
6*	882	Krajewski, T.	1969		78-148		The above specimen; expansion measured along b-axis; this curve is here reported using the first temperature (78 K) as reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

DATA TABLE 193. THERMAL LINEAR EXPANSION OF POTASSIUM DIHYDROGEN ORTHOPHOSPHATE KH_2PO_4

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
119	-0.311
126	-0.323
128	-0.340
129	-0.365
146	-0.339
188	-0.258
281	-0.077
297	0.026
323	0.058
CURVE 2	
91	-0.661
123	-0.591
126	-0.598
128	-0.607
129	-0.639
198	-0.390
259	-0.147
295	0.00
324	0.161
CURVE 3‡	
121	-0.661
122	-0.660
122	-0.660*
123	-0.657
124	-0.653
125	-0.648*
128	-0.640
133	-0.622
144	-0.586
149	-0.567
157	-0.539
281	-0.048
289	-0.017
293	0.000
CURVE 4‡	
293	0.000*
309	0.037
313	0.047
314	0.049*
325	0.077
CURVE 4 (cont.)‡	
325	0.077*
333	0.098
335	0.104
337	0.109
341	0.120
342	0.123
352	0.149
353	0.152
362	0.176
363	0.176
363	0.178*
375	0.206
376	0.208*
377	0.210
380	0.215
382	0.218
CURVE 5*, †, ‡	
77	0.000
84	0.329
91	0.658
100	1.054
112	1.534
114	1.612
116	1.686
119	1.765
121	1.801
125	1.795
126	1.669
127	1.192
CURVE 6*, †, ‡	
78	0.000
84	0.450
91	0.982
100	1.688
112	2.660
114	2.822
116	2.984
119	3.163
122	3.214
126	3.334
127	3.631

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 193. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POTASSIUM DIHYDROGEN ORTHOPHOSPHATE KH_2PO_4

{Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\ K^{-1}$}

T	α
CURVE 3‡	
84	28.0
89	25.1
93	25.1
102	23.0
105	23.0
109	16.9
111	12.9
114	7.6
116	-9.1
117	-19.1
117	-23.4
118	-62.3
119	-88.7
120	-123.5
120	-167.9
120	-216.8
119	-256.6
121	-67.0
121	5.1
122	21.5
122	26.2
123	31.2
124	32.9*
125	32.9*
128	32.9*
133	32.9
144	35.9
149	34.4
157	36.4
281	42.6
289	42.8
293	44.2
CURVE 4*,‡	
293	22.3
309	24.2
313	24.1
314	24.6
325	26.2
333	26.9
335	26.9
337	27.1
341	27.3
342	26.8
352	26.5

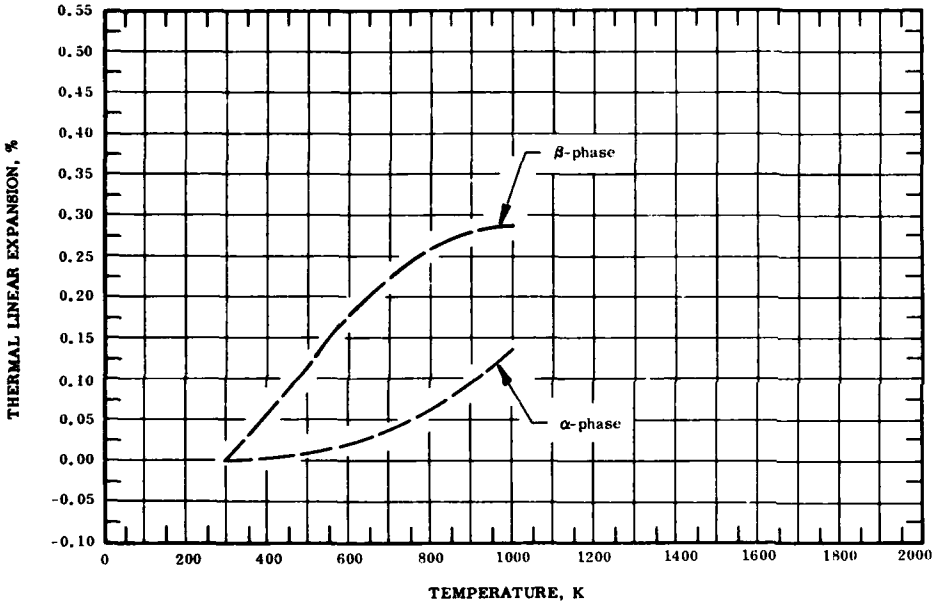
T	α
CURVE 4 (cont.)*,‡	
353	26.8
362	25.5
362	25.0
363	25.3
375	20.7
376	20.4
377	20.6
380	16.3
382	10.3
384	-3.7
386	5.1
386	9.0
386	11.1
386	18.0
386	19.2
387	19.9
387	25.9
388	20.5
390	25.7
391	26.3
398	26.0
403	25.8
412	25.3
414	25.2
419	24.8
428	24.3
435	23.5
453	21.4
476	17.6
CURVE 5‡	
77	4.7
84	4.7*
91	4.7
100	4.1
112	3.9
114	3.9*
116	3.5
119	1.8
121	1.8*
125	-2.1
126	-23.1
127	-72.3
128	14.3
137	19.0
146	20.6

T	α
CURVE 6‡	
78	7.4
84	7.6
91	7.6*
100	8.1
112	8.1*
114	8.1*
116	8.1
119	3.8*
122	-0.4
126	6.4
127	53.1
128	17.1
133	18.2
141	19.7
148	21.1

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 194R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ZINC ORTHOPHOSPHATE $Zn_3(PO_4)_2$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	α-phase		β-phase	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	0.2	0.000	5.8
400	0.005	0.4	0.06	5.9
500	0.010	0.8	0.122	5.7
600	0.021	1.4	0.175	5.1
700	0.038	2.0	0.22	4.2
800	0.062	2.8	0.257	3.0
900	0.096	3.8	0.28	1.4
1000	0.137	4.8	0.285	-0.4

REMARKS

The provisional values for the α- and β-phase are considered accurate to within ±10% and are represented approximately by the following equations:

α-phase: $\Delta L/L_0 = -0.002 + 1.993 \times 10^{-5} T - 1.052 \times 10^{-7} T^2 + 2.247 \times 10^{-10} T^3$

β-phase: $\Delta L/L_0 = -0.145 + 3.613 \times 10^{-4} T + 6.106 \times 10^{-7} T^2 - 5.415 \times 10^{-10} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±15%.

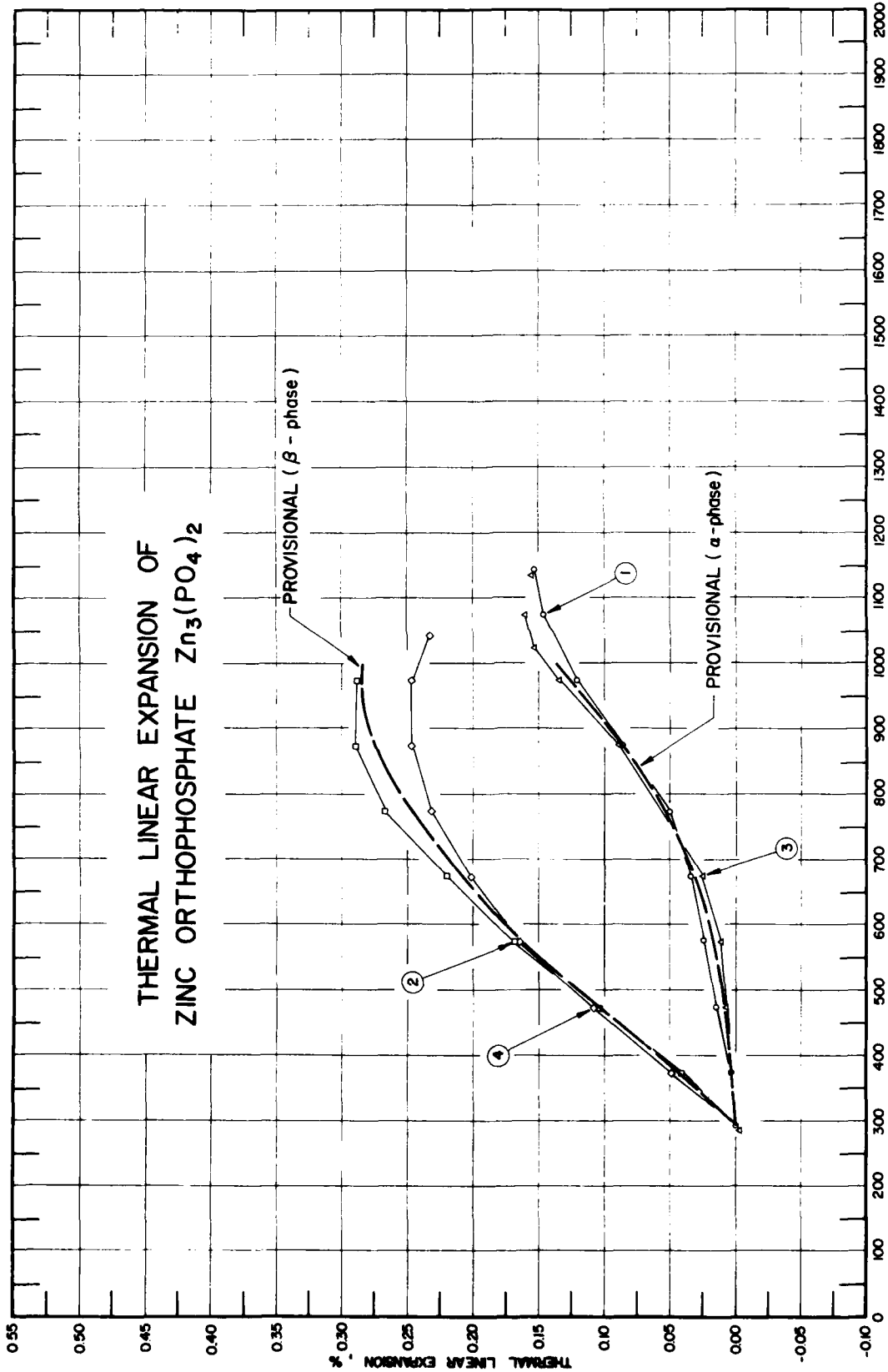

THERMAL LINEAR EXPANSION OF
ZINC ORTHOPHOSPHATE $Zn_3(PO_4)_2$
PROVISIONAL (β - phase)
PROVISIONAL (α - phase)
1
2
3
4
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 194

SPECIFICATION TABLE 194. THERMAL LINEAR EXPANSION OF ZINC ORTHOPHOSPHATE $Zn_3(PO_4)_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	725	Brown, J.J., Jr. and Hummel, F.A.	1965	L	297-1142	α-Z_3P	Phase α-$Zn_3(PO_4)_2$; 1 cm x 1 cm x 10 cm bar; batches of C.P. grade, mixed, air-dried, heated slowly in a Globar furnace to 600 C, remixed, allowed to react and to equilibrate at 900 C before being ground, mixed with a Carbowax solution and pressed into bar at 1000 psi; bar fired to 915 C; aggregate thermal expansion measured, heating rate 120 C per hour.
2	725	Brown, J.J., Jr. and Hummel, F.A.	1965	L	297-1033	β-Z_3P	Phase β-$Zn_3(PO_4)$; similar to the above specimen but the calcined temperature is 1000 C and bar fired to 1025 C.
3	333	Brown, J.J., Jr.	1964	L	288-1135	α-Z_3P	Bar specimen, approximately 10 x 1 x 1 cm; heated at 125 C per hr in Nichrome-Wound vertical tube furnace; data from smoothed curve.
4	333	Brown, J.J., Jr.	1964	L	288-1042	β-Z_3P	Similar to the above specimen except of different phase.

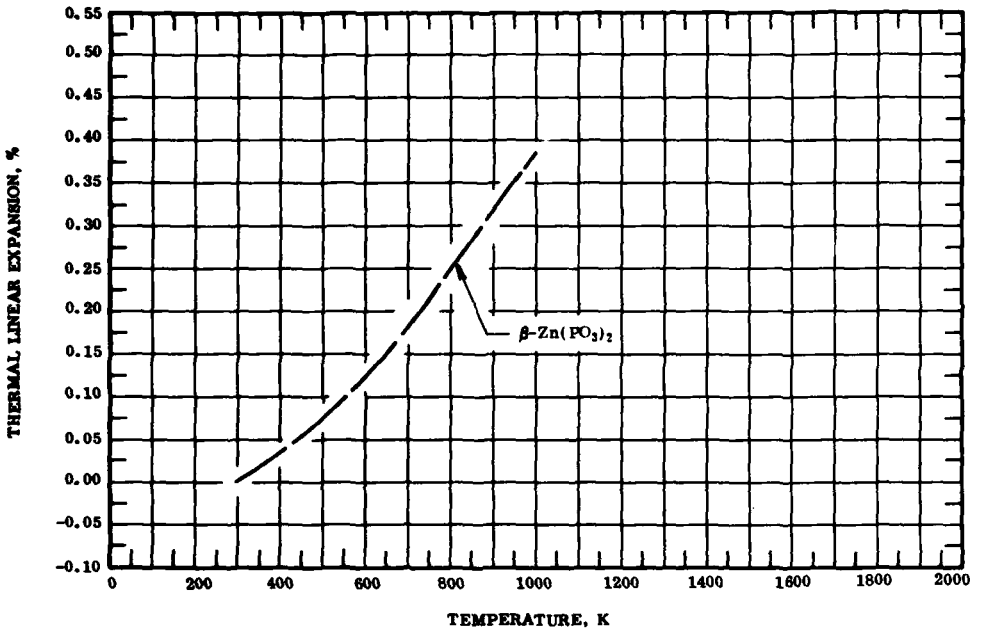
DATA TABLE 194. THERMAL LINEAR EXPANSION OF ZINC ORTHOPHOSPHATES $Zn_3(PO_4)_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
373	0.003
473	0.015
573	0.025
673	0.036
773	0.051
873	0.086
973	0.122
1073	0.147
1142	0.154
CURVE 2	
293	0.000*
373	0.041
473	0.103
573	0.168
673	0.221
773	0.267
873	0.290
973	0.289
1015	0.298
1033	0.339
CURVE 3	
288	-0.003
293	0.000*
373	0.004*
473	0.007
573	0.012
673	0.026
773	0.051*
873	0.088
973	0.135
1023	0.154
1073	0.161
1135	0.156
CURVE 4	
288	-0.005*
293	0.000*
373	0.049
473	0.108
573	0.166
673	0.202
773	0.232
873	0.247
973	0.247
1042	0.234

* Not shown in figure.

FIGURE AND TABLE NO. 195R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ZINC METAPHOSPHATE $Zn(PO_3)_2$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, $10^{-6}\ K^{-1}$]

T	$\Delta L/L_0$	α
293	0.000	2.2
400	0.031	3.6
500	0.073	4.7
600	0.124	5.5
700	0.182	6.2
800	0.247	6.6
900	0.318	6.8
1000	0.382	6.9

REMARKS

The provisional values for the β-$Zn(PO_3)_2$ are considered accurate to within ±10% and are represented approximately by the following equation:

$$\Delta L/L_0 = 0.006 - 2.899 \times 10^{-4}\,T + 1.027 \times 10^{-6}\,T^2 - 3.604 \times 10^{-10}\,T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±15%.

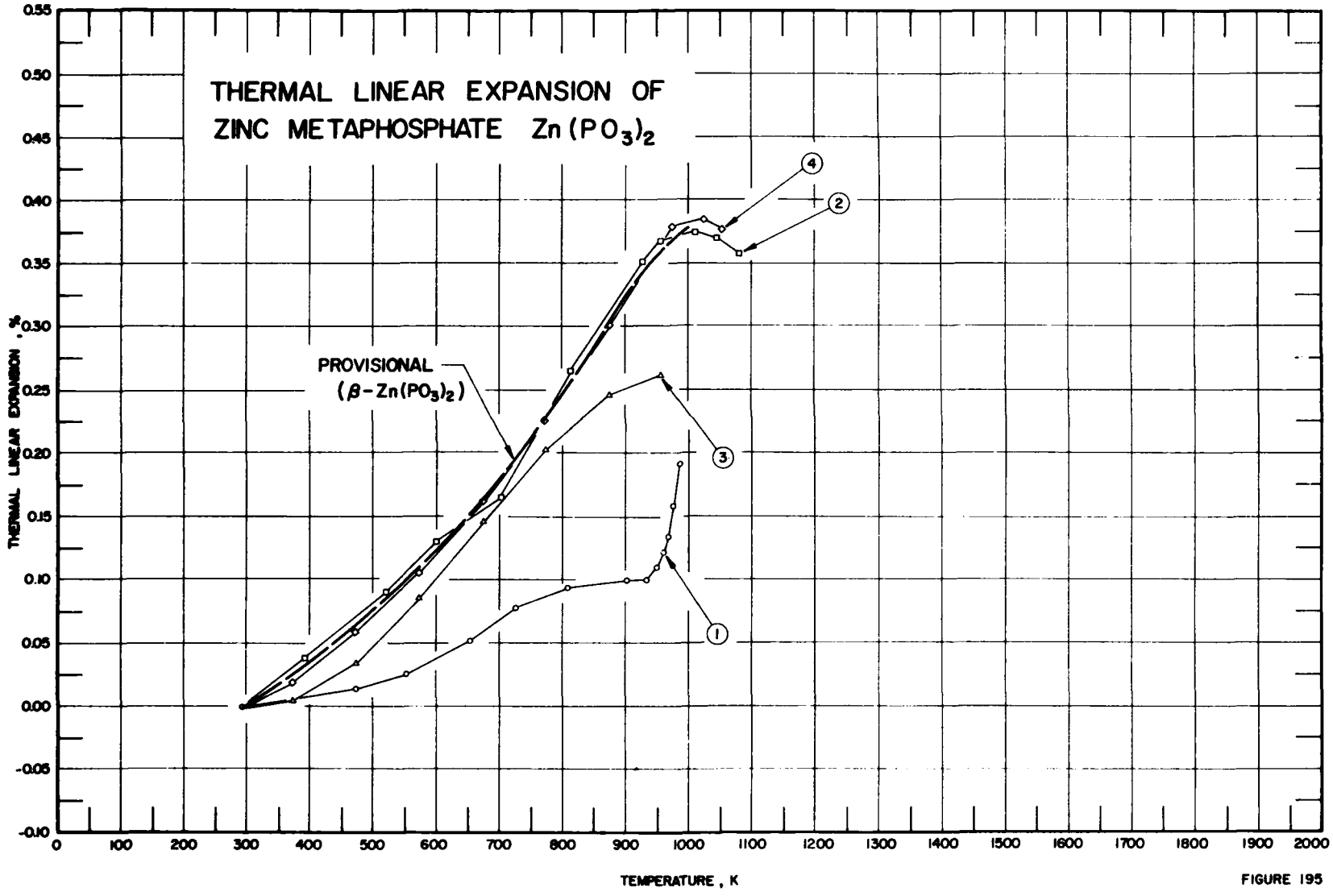

THERMAL LINEAR EXPANSION OF
ZINC METAPHOSPHATE Zn(PO3)2
PROVISIONAL
(β-Zn(PO3)2)
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
4

FIGURE 195

SPECIFICATION TABLE 195. THERMAL LINEAR EXPANSION OF ZINC METAPHOSPHATE $Zn(PO_3)_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	725	Brown, J.J. and Hummel, F.A.	1965	L	298-873	α-$Zn(PO_3)_2$	Phase α-$Zn(PO_3)_2$; 10 cm x 1 cm x 1 cm bar; batches mixed, air-dried, heated slowly in a Globar furnace to 600 C; remixed, and allowed to equilibrate at 625 C in 72 hours before being ground, mixed with a Carbowax solution and pressed into bar at 1000 psi; bar heated at 60 C 1 hr to 620 C; aggregate thermal expansion measured using heating rate 120 C/hour.
2	725	Brown, J.J. and Hummel, F.A.	1965	L	298-973	β-$Zn(PO_3)_2$	β-$Zn(PO_3)_2$ phase; bar fired to 825 C in 4 hours; similar to the above specimen.
3	333	Brown, J.J., Jr.	1964	L	288-958	α-ZP	Bar specimen, approximately 10 x 1 x 1 cm; heated at 125 C per hr in Nichrome-Wound vertical tube furnace; data from smoothed curve.
4	333	Brown, J.J., Jr.	1964	L	288-1054	β-ZP	Similar to the above specimen except of different phase; data from smoothed curve.
5*	727	Krause, J.T. and Kurkjian, C.R.	1968	L	4.2-37		This curve is here reported using the first temperature (4.2 K) as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 195. THERMAL LINEAR EXPANSION OF ZINC METAPHOSPHATE $Zn(PO_3)_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
475	0.015
553	0.026
654	0.052
729	0.078
810	0.094
902	0.100
933	0.100
950	0.110
961	0.122
969	0.134
977	0.158
987	0.192
CURVE 2	
293	0.000*
393	0.038
521	0.090
600	0.131
702	0.189
814	0.265
929	0.352
958	0.368
1010	0.375
1043	0.371
1080	0.358
CURVE 3	
288	-0.003
293	0.000*
373	0.004
473	0.035
573	0.086
673	0.147
773	0.203
873	0.247
958	0.262
CURVE 4	
288	-0.003*
293	0.000*
373	0.019
473	0.059
573	0.106
673	0.163
773	0.226
873	0.301
973	0.379
1023	0.386
1054	0.378
CURVE 5*	
4	0.000
6	0.007
7	-0.001
8	-0.002
9	-0.005
10	-0.006
12	-0.012
14	-0.019
16	-0.027
18	-0.035
20	-0.041
22	-0.051
24	-0.061
25	-0.067
27	-0.075
29	-0.081
31	-0.086
37	-0.092

* Not shown in figure.

SPECIFICATION TABLE 196. THERMAL LINEAR EXPANSION OF ZIRCONIUM PHOSPHATES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	91	Hummel, F.A.	1946		298-1075		Zirconium orthophosphate; pure specimen, calcined at 1673 K and formed into bars.
2*	728	Harrison, D.E., McKinstry, H.A., and Hummel, F.A.	1954	L	352-1273	ZrP_2O_7 ("normal" phosphate)	Zirconium pyrophosphate; 53.5 P_2O_5, 46.5 ZrO_2, prepared by direct mixing of 112.2 gm Zirconium oxychloride from Titanium Alloy Manufacturing Division, National Lead Co. contains 41.5 ZrO_2, and 51.5 c.c. 85% c.p. phosphoric acid in ball mill, resultant gel discharged into Pyrex-brand glass beaker, dried at 110 C, calcined at 1380 C for 10 hr in pint dish, bar sample about 1 sq. cm cross section, 10 cm long, compacted at 2000 C, 16 per sq. in., fired in Globar furnace at 1200 C for 5 hr, at 1380 C for 5 to 10 hr; other high-temperature firings at 1515 C for 4 hr and 1550 C for 4 hr made in gas-fired pot furnace, and several firings at 1600 C to 1700 C for 1 to 2 hr made in Remmey No. 2350 furnace using propane-air mixture as fuel; inversion near 300 C transition from low-temperature cubic form to high-temperature cubic form.
3*	729	Pole, G.R., Beinlich, A.W., and Gilbert, N.	1946	L	293-1443	ZrP_2O_7 ($ZrO_2 \cdot P_2O_5$)	Zirconium pyrophosphate; specimen prepared in T.V.A. laboratory P_2O_5 - 53.5, and ZrO_2 - 46.5; specimen size 3" x 1" x 1"; heating rate 4 C per min.
4*	728	Harrison, D.E., McKinstry, H.A., and Hummel, F.A.	1954	L	338-1249	$Zr_2P_2O_9$	Zirconium phosphate; 63.4 ZrO_2, 36.6 P_2O_5, prepared by direct mixing of 153 gm zirconium oxychloride from Titanium Alloy Manufacturing Division, National Lead Co. contains 41.5 ZrO_2, and 35.2 cc 85% c.p. phospheric acid in ball mill, resultant get discharged into Pyrex-brand glass beaker, dried at 110 C, calcined at 1550 C for 4 hr, pressed into bar about 1 sq. cm cross section 10 cm long, compacted at 2000 lb per sq. in.; fired in Globar furnace at 1200 C for 5 hr, at 1380 C for 5 hr, other high-temperature firings at 1515 C for 4 hr and 1550 C for 4 hr made in gas-fired pot furnace and several firings at 1600 C to 1700 C for 1 to 2 hr, made in Rommey No. 2350 furnace using propane-air mixture as fuel.

* No figure given.

DATA TABLE 196. THERMAL LINEAR EXPANSION OF ZIRCONIUM PHOSPHATES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
298	0.002
323	0.014
372	0.014
426	0.017
471	0.020
521	0.023
572	0.026
620	0.029
662	0.029
721	0.080
772	0.140
820	0.211
871	0.254
921	0.297
972	0.341
1023	0.389
1075	0.434
CURVE 2*	
352	0.061
382	0.092
397	0.112
426	0.141
450	0.167
494	0.226
535	0.300
564	0.393
579	0.559
593	0.574
623	0.595
652	0.608
710	0.631
756	0.652
762	0.657
788	0.667
834	0.675
860	0.680
907	0.689
937	0.696
966	0.698
1053	0.705
1069	0.708
1105	0.706
1157	0.710
1186	0.710
1209	0.713
1240	0.715
1273	0.718
CURVE 3*	
293	0.000
333	0.000
373	0.000
473	0.000
573	0.000
673	0.000
773	0.002
873	0.002
973	0.002
1073	0.004
1173	0.004
1273	0.004
1373	0.004
1443	0.004
CURVE 4*	
338	0.000
362	0.000
403	0.000
459	0.001
567	0.003
595	0.004
635	0.006
665	0.008
706	0.010
749	0.015
804	0.020
862	0.030
926	0.042
989	0.054
1054	0.069
1096	0.084
1133	0.094
1178	0.109
1249	0.133

* No figure given.

SPECIFICATION TABLE 197. THERMAL LINEAR EXPANSION OF MISCELLANEOUS PHOSPHATES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	315	Hummel, F.A.	1949	X	293-1273	$AlPO_4$ Cristobalite type	Aluminum orthophosphate; specimen prepared by precipitation from solution of aluminum nitrate, then quartz type of crystal formed; dried at 383 K, followed by heat-treatments in air; cristobalite type of crystal formed; calcined at 1773 K for 1 hr and refired at 1773 K for 2 hr with 6% aluminum metaphosphate bond; data from smoothed curve.
2*	315	Hummel, F.A.	1949	X	298-613	$AlPO_4$ Cristobalite type	Aluminum orthophosphate; data from smoothed curve.
3*	315	Hummel, F.A.	1949	X	613-273	$AlPO_4$ Cristobalite type	Aluminum orthophosphate; the above specimen; expansion measured with decreasing temperature; zero-point correction of -0.12%.
4*	723	Beck, W.R.	1949	L	293-833	$AlPO_4$	Aluminum orthophosphate; amorphous commercial aluminum phosphates 1/2 in. diameter, 3 in. long of Tridymite form; obtained from Baker and Mallinckrodt with traces of Mg, Si, Na, Ca, V, and Fe; gauge measurement to 0.0001 in.; zero-point correction 0.051%.
5*	723	Beck, W.R.	1949	L	293-1085	$AlPO_4$	Aluminum orthophosphate; similar to the above specimen; data for Cristobalite form; zero-point correction 0.022%.
6*	287	Cook, W.R.	1967	I	136-322	$NH_4H_2PO_4$	Ammonium dihydrogen orthophosphate; sample length 7.3 mm; expansion measured along a- and b-axis of orthorhombic crystal and along a-axis of tetragonal structure above the Curie point 147 K, respectively; total contraction from 298 K to Curie point 0.408%.
7*	287	Cook, W.R.	1967	I	138-322	$NH_4H_2PO_4$	Ammonium dihydrogen orthophosphate; similar to the above specimen; sample length 6.1 mm; total contraction from 298 K to Curie point 0.162%.
8*	724	Boiko, A.A. and Golovnin, V.A.	1970	X	109-293	$NH_4H_2PO_4$	Ammonium dihydrogen orthophosphate; transition temperature at 151 K from orthorhombic structure to tetragonal structure; averaged values of heating and cooling lattice constant; expansion measured along a-axis; 7.499 Å of tetragonal structure reported at 293 K.
9*	724	Boiko, A.A. and Golovnin, V.A.	1970	X	108-151	$NH_4H_2PO_4$	Ammonium dihydrogen orthophosphate; the above specimen; lattice constant expansion of orthorhombic structure measured along b-axis; 7.5166 Å reported at 108 K.
10*	724	Boiko, A.A. and Golovnin, V.A.	1970	X	108-293	$NH_4H_2PO_4$	Ammonium dihydrogen orthophosphate; the above specimen; lattice constant expansion measured along c-axis; 7.4664 Å reported at 108 K for orthorhombic structure; 7.5490 Å reported at 293 K for tetragonal structure.
11*	42	Kirchner, H.P., Merz, K.M., and Smyth, H.T.	1959	L	293-993	$Co_3(PO_4)_2$ ($3CoO \cdot P_2O_5$)	Cobalt orthorphosphate; bar specimen 4.37 in. long, 0.44 in. square; prepared by treating a solution of cobalt nitrate with sodium hydrophosphate, resulting flakes heated to 673 K in hydrogen atmosphere for 2 hr, resulting powder mixed with 15% binder solution, pressed at 5000 psi and fired at 1173 K for 2 hr and produce a matured body; reported error ±2%.

* No figure given.

SPECIFICATION TABLE 197. THERMAL LINEAR EXPANSION OF MISCELLANEOUS PHOSPHATES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
12*	289	Shafer, E.C. and Roy, R.	1956	X	290-1340	$GaPO_4$	Gallium orthophosphate; quartz form specimen; prepared by mixing δ-Ga_2O_3 and 85% H_3PO_4 into slurry in platinum crucible and heating to 873 K; expansion measured in (200) crystal plane.
13*	289	Shafer, E.C. and Roy, R.	1956	X	290-1339	$GaPO_4$	Gallium orthophosphate; the above specimen; expansion measured in (111) crystal plane.
14*	289	Shafer, E.C. and Roy, R.	1956	X	290-1334	$GaPO_4$	Gallium orthophosphate; the above specimen; expansion measured in (102) crystal plane.
15*	289	Shafer, E.C. and Roy, R.	1956	X	290-1340	$GaPO_4$	Gallium orthophosphate; the above specimen; expansion measured in (112) crystal plane.
16*	725	Brown, J.J. and Hummel, F.A.	1965	L	298-1123	$Mg(PO_3)_2$	Magnesium metaphosphate; 1 x 1 x 10 cm bar, batches of c.p. grades, mixed, air-dried, heated slowly in Globar furnace to 600 C, remixed, and allowed to equilibrate at 1000 C in 48 hr before being ground, mixed with Carbowax solution and pressed into bar at 1000 psi; bar heated to 975 C; aggregate thermal expansion measured using heating rate 120 C/hr.
17*	333	Brown, J.J., Jr.	1964	L	293-1173	$NbPO_5$ (αNP)	Niobium phosphate; bar specimen, approx 10 x 1 x 1 cm; Nb_2O_5 and P_2O_5 mixed by molar ratio 1:1; heated at 125 C per hr in Nichcrome- wound vertical tube furnace; data from smoothed curve.
18*	333	Brown, J.J., Jr.	1964	L	293-1270	$NbPO_5$ (βNP)	Niobium phosphate; similar to the above specimen except in different phase.
19*	287	Cook, W.R.	1967	I	121-326	KD_2PO_4	Potassium Dideuterium orthophosphate; specimen length 4.9 mm; expansion measured as average of a- and b-axis of orthorhombic structure below Curie point 222 K; and a-axis of tetragonal structure above Curie point; 7.4697 Å for tetragonal structure reported at 298 K; total contraction from 298 K to Curie point 0.151%.
20*	287	Cook, W.R.	1967	I	212-324	KD_2PO_4	Potassium dideuterium orthophosphate; similar to the above specimen; specimen length 3.9 mm; expansion measured along c-axis; zero-point correction 0.015%; 6.9766 Å for tetragonal structure reported at 298 K; total contraction from 298 K to Curie point 0.296%; zero-point correction 0.036%.
21*	741	Despande, V.T. and Khan, A.A.	1966	X	293-351	RbH_2PO_4	Rubidium dihydrogen orthophosphate; prepared by slow evaporation of an aqueous solution of rubidium carbonate neutralized with an aqueous solution of hypophosphoric acid; using CuKα radiation measured along a-axis; 7.6054 Å reported at 293 K; reported error 0.013%.
22*	741	Despande, V.T. and Khan, A.A.	1966	X	293-351	RbH_2PO_4	Rubidium dihydrogen orthophosphate; the above specimen; measured along c-axis; 7.2987 Å reported at 293 K; reported error 0.019%.
23*	739	Smolenko, L.A., Sidnenko, E.V., and Zheludev, I.S.	1967	L	147-293	RbH_2PO_4	Rubidium dihydrogen orthophosphate; dilatometer sensitivity 170 Å, accuracy to 1-3% (10-20° steps) 15-20% for (0.5-1° steps) near T_C specimen linear dimensions of 1 cm curve along a four-fold axis ($\alpha_{33} = \alpha_3$).
24*	333	Brown, J.J., Jr.	1964	L	293-1270	$TaPO_5$	Tantalum phosphate; bar specimen approximately 10 x 1 x 1 cm; Ta_2O_5 and P_2O_5 mixed by molar ratio 1:1; heated at 125 C per hr inNichcrome-wound vertical tube furnace; data from smoothed curve.

* No figure given.

SPECIFICATION TABLE 197. THERMAL LINEAR EXPANSION OF MISCELLANEOUS PHOSPHATES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
25*		Kirchner, H.P., Merz, K.M., and Smyth, H.T.	1959	L	293-1053	$Sn_3(PO_4)_2$ ($3SnO \cdot P_2O_5$)	Tin orthophosphate; prepared by pouring a 10% solution of sodium hydrophosphate into a saturated solution of stannous sulphate (1:10) acidified with H_2SO_4; the precipitate was washed with hot water, boiled with water, washed with alcohol and ether and dried over P_2O_5; the dried powder mixed with 15% binder; pressed into a bar 4 3/8 in. long by 7/16 in. square at 5000 psi and fired at 1100 C for two hr; traces of $SnSO_4$ and $Na_4P_2O_7$; reported error ±2%.
26	3	Brown, J.J., Jr.	1964	L	293-879	VPO_5	Vanadium phosphate; bar specimen approximately 10 x 1 x 1 cm; V_2O_5 and P_2O_5 mixed by molar ratio 1:1; heated at 125 C per hr in Nichrome-Wound vertical tube furnace; data from smoothed curve.
27*	725	Brown, J.J. and Hummel, F.A.	1965	L	294-1143	$Zn_2P_2O_7$	Zinc pyrophosphate; phase α-$Zn_2P_2O_7$; 1 x 1 x 10 cm bar; batches of c.p. grade mixed, air-dried, heated slowly in a Globar furnace to 600 C, remixed and allowed to equilibrate at 975 C in 48 hr before being ground, mixed with a carbowax solution and pressed into bar at 1000 psi; bar fired to 975 C; heating rate for thermal expansion measurements 120 C/hour.
28*	333	Brown, J.J., Jr.	1964	L	288-1180	$Zn_2P_2O_7$ (Z_2P)	Zinc pyrophosphate; bar specimen, approximately 10 x 1 x 1 cm; heated at 125 C per hr in Nichrome-Wound vertical tube furnace; α-$Zn_2P_2O_7$ inverted to β-$Zn_2P_2O_7$ at 405 K; data from smoothed curve.

* No figure given.

DATA TABLE 197. THERMAL LINEAR EXPANSION OF MISCELLANEOUS PHOSPHATES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
293	0.00
341	0.06
372	0.13
399	0.20
424	0.29
447	0.41
470	0.55
506	1.36
518	1.48
530	1.56
554	1.63
573	1.64
626	1.68
674	1.71
730	1.75
773	1.77
828	1.79
874	1.79
974	1.80
1072	1.81
1173	1.82
1273	1.82

CURVE 2*

T	$\Delta L/L_0$
293	0.00
325	0.05
371	0.16
401	0.25
431	0.38
452	0.51
462	0.63
473	1.01
481	1.44
489	1.50
512	1.54
557	1.58
613	1.63

CURVE 3*

T	$\Delta L/L_0$
613	1.51
545	1.49
477	1.40
470	1.35

CURVE 3 (cont.)*

T	$\Delta L/L_0$
466	1.29
446	0.53
440	0.46
423	0.38
372	0.21
323	0.07
293	0.00
273	-0.04

CURVE 4*

T	$\Delta L/L_0$
293	0.000
333	0.051
353	0.090
360	0.199
365	0.266
373	0.280
393	0.313
413	0.378
433	0.429
453	0.475
473	0.512
493	0.547
513	0.576
533	0.610
553	0.635
573	0.673
593	0.695
613	0.728
633	0.749
653	0.778
673	0.795
693	0.815
713	0.829
733	0.848
753	0.860
773	0.869
793	0.872
813	0.870
833	0.857

CURVE 5*

T	$\Delta L/L_0$
293	0.000
313	0.022

CURVE 5 (cont.)*

T	$\Delta L/L_0$
333	0.061
353	0.086
373	0.121
393	0.154
413	0.187
433	0.226
453	0.274
466	0.317
473	0.365
482	0.659
493	0.750
500	0.770
513	0.792
533	0.817
553	0.838
573	0.851
593	0.869
613	0.884
633	0.896
653	0.912
673	0.925
693	0.948
713	0.964
733	0.988
753	0.999
773	1.002
793	1.006
813	1.009
833	1.009
853	1.017
873	1.022
893	1.022
913	1.022
933	1.022
953	1.022
973	1.022
993	1.022
1013	1.022
1033	1.019
1053	1.018
1085	1.010

CURVE 6*

T	$\Delta L/L_0$
136	0.178

CURVE 6 (cont.)*

T	$\Delta L/L_0$
142	0.177
146	0.166
147	-0.396
166	-0.360
207	-0.261
237	-0.176
282	-0.033
322	0.103

CURVE 7*

T	$\Delta L/L_0$
138	-0.882
145	-0.843
146	-0.145
169	-0.100
190	-0.067
221	-0.034
256	-0.011
291	0.004
322	0.009

T	a(Å)

CURVE 8*

109	7.4933
120	7.4939
123	7.4940
125	7.4940
128	7.4942
132	7.4944
137	7.4947
139	7.4947
141	7.4947
130	7.4947
144	7.4948
145	7.4948
146	7.4948
147	7.4948
148	7.4948
149	7.4948
149	7.4690

CURVE 8 (cont.)*

T	$\Delta L/L_0$
151	-0.400
152	-0.398
154	-0.392
155	-0.388
161	-0.377
164	-0.368
169	-0.361
173	-0.350
175	-0.342
178	-0.336
180	-0.330
182	-0.332
184	-0.325
186	-0.320
189	-0.312
191	-0.309
193	-0.301
195	-0.297
197	-0.294
202	-0.282
205	-0.270
206	-0.268
208	-0.261
211	-0.252
215	-0.249
218	-0.233
221	-0.225
225	-0.216
226	-0.213
228	-0.204
230	-0.201
232	-0.193
238	-0.182
241	-0.174
242	-0.166
244	-0.161
247	-0.149
249	-0.144
251	-0.137
254	-0.128
259	-0.108
262	-0.104
266	-0.092
268	-0.078
277	-0.046
293	0.000

CURVE 9*

T	b(Å)
108	7.5166
113	7.5164
118	7.5165
119	7.5162
123	7.5162
125	7.5162
126	7.5161
128	7.5162
130	7.5161
132	7.5162
135	7.5161
137	7.5158
139	7.5158
141	7.5157
143	7.5157
144	7.5155
146	7.5155
147	7.5153
148	7.5153
149	7.5146
151	7.5146

T	c(Å)

CURVE 10*

108	7.4664
110	7.4668
114	7.4679
118	7.4689
121	7.4705
124	7.4718
134	7.4742
143	7.4777
147	7.4781
148	7.4801
148	7.4810
149	7.4819

T	$\Delta L/L_0$
149	-0.239
150	-0.226
151	-0.197
152	-0.165
153	-0.141

* No figure given.

DATA TABLE 197. THERMAL LINEAR EXPANSION OF MISCELLANEOUS PHOSPHATES (continued)

T	$\Delta L/L_0$
CURVE 10 (cont.)*	
155	-0.110
166	-0.087
175	-0.072
185	-0.058
194	-0.045
203	-0.034
211	-0.022
216	-0.011
222	-0.011
238	-0.008
247	-0.008
255	-0.008
263	-0.008
272	-0.008
293	0.000
CURVE 11*	
293	0.000
353	0.020
388	0.040
433	0.065
453	0.080
493	0.100
521	0.120
551	0.140
573	0.160
613	0.180
648	0.215
683	0.235
713	0.270
733	0.290
773	0.320
833	0.380
863	0.410
913	0.465
993	0.540
CURVE 12*	
290	-0.06
372	0.29
449	0.58
531	0.88
622	1.19
717	1.47

T	$\Delta L/L_0$
CURVE 12 (cont.)*	
818	1.76
921	2.04
1058	2.34
1164	2.55
1258	2.72
1340	2.82
CURVE 13*	
290	-0.06
371	0.27
469	0.63
586	1.03
739	1.50
866	1.84
1010	2.15
1180	2.45
1339	2.65
CURVE 14*	
290	-0.06
382	0.29
505	0.71
602	1.04
713	1.32
835	1.61
967	1.85
1119	2.05
1235	2.17
1334	2.22
CURVE 15*	
290	-0.06
399	0.31
512	0.67
624	0.96
728	1.20
868	1.47
1007	1.66
1179	1.80
1340	1.85

T	$\Delta L/L_0$
CURVE 16*	
289	0.000
358	0.030
447	0.085
608	0.205
772	0.344
883	0.440
1037	0.588
1076	0.624
1096	0.638
1134	0.645
CURVE 17*	
293	0.000
373	0.016
473	0.036
573	0.059
673	0.081
773	0.104
873	0.128
973	0.155
1073	0.181
1173	0.209
CURVE 18*	
293	0.000
373	0.066
445	0.134
473	0.153
502	0.164
573	0.170
673	0.178
773	0.187
873	0.197
973	0.211
1073	0.234
1173	0.263
1270	0.294
CURVE 19*	
121	-0.295
177	-0.213
221	-0.138
233	-0.121

T	$\Delta L/L_0$
CURVE 19 (cont.)*	
282	-0.024
307	-0.031
326	0.078
CURVE 20*	
212	-0.187
220	-0.175
223	-0.184
224	-0.267
253	-0.165
292	0.000
324	0.163
CURVE 21*	
293.2	0.000
302.2	0.031
308.2	0.034
323.2	0.079
334.7	0.126
347.2	0.150
351.2	0.158
CURVE 22*	
293.2	0.000
302.2	0.051
308.2	0.069
323.2	0.164
334.7	0.205
347.2	0.284
351.2	0.301
CURVE 23*,‡	
147.1	-0.619
147.1	-0.619
148.4	-0.614
149.7	-0.609
153.4	-0.595
160.5	-0.568
278.8	-0.066
288.4	-0.021
293.0	0.000

T	$\Delta L/L_0$
CURVE 24*	
293	0.000
373	0.034
473	0.107
573	0.206
656	0.306
673	0.312
773	0.312
873	0.313
973	0.313
1073	0.315
1173	0.315
1270	0.315
CURVE 25*	
293	0.000
328	0.005
383	0.038
493	0.125
623	0.250
748	0.400
873	0.540
1003	0.730
1053	0.870
CURVE 26*	
293	0.000
373	0.084
473	0.179
573	0.275
673	0.372
773	0.468
873	0.561
879	0.569
CURVE 27*	
294	0.001
321	0.017
341	0.019
365	0.017
386	-0.004
394	-0.020
427	-0.810
435	-0.816

T	$\Delta L/L_0$
CURVE 27 (cont.)*	
1032	-0.389
1050	-0.378
1067	-0.372
1096	-0.368
1115	-0.372
1133	-0.378
1143	-0.395
CURVE 28*	
288	0.00
923	0.00
363	0.00
373	-0.01
389	-0.03
436	-0.76
449	-0.80
473	-0.81
573	-0.74
673	-0.67
773	-0.60
873	-0.53
973	-0.46
1073	-0.40
1103	-0.39
1123	-0.40
1158	-0.42
1173	-0.44
1180	-0.45

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 198. THERMAL LINEAR EXPANSION OF POTASSIUM TRIHYDROGEN SELENITE $KH_3(SeO_3)_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	981	Tivari, H.W. and Narayanan, P.S.	1972	I	123-302		Transparent single crystal specimen 4 x 1.2 x 0.7 cm; grown from aqueous solution of calcium hydroxide and selenious acid taken in stoichiometric ratio by slow vaporization at room temperature using reversing-rotation technique; expansion measured along a-axis of rhombic phase.
2*	981	Tivari, H.W. and Narayanan, P.S.	1972	I	123-302		The above specimen; expansion measured along b-axis of rhombic phase.
3*	981	Tivari, H.W. and Narayanan, P.S.	1972	I	125-298		The above specimen; expansion measured along c-axis of rhombic phase.

* No figure given.

DATA TABLE 198. THERMAL LINEAR EXPANSION OF POTASSIUM TRIHYDROGEN SELENITE $KH_3(SeO_3)_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 2 (cont.)*,‡		CURVE 3 (cont.)*,‡		CURVE 3 (cont.)*,‡	
212	-0.201	183	-0.556	169	-0.571	293	0.000
217	-0.189	188	-0.537	173	-0.550	295	0.009
218	-0.186	193	-0.518	175	-0.540	298	0.021
221	-0.179	198	-0.499	178	-0.524		
223	-0.175	201	-0.487	181	-0.508		
225	-0.171	203	-0.478	184	-0.492		
227	-0.166	207	-0.460	187	-0.475		
230	-0.160	209	-0.450	190	-0.458		
233	-0.153	211	-0.440	193	-0.441		
236	-0.146	213	-0.429	195	-0.429		
239	-0.140	214	-0.423	198	-0.411		
242	-0.133	216	-0.413	200	-0.398		
245	-0.126	218	-0.403	202	-0.386		
248	-0.120	223	-0.379	203	-0.379		
250	-0.115	228	-0.355	203	-0.379		
253	-0.108	233	-0.332	205	-0.366		
256	-0.101	238	-0.307	206	-0.360		
259	-0.093	240	-0.297	206	-0.360		
262	-0.085	243	-0.281	208	-0.346		
265	-0.077	253	-0.228	208	-0.346		
269	-0.067	258	-0.201	209	-0.339		
272	-0.058	263	-0.173	209	-0.339		
277	-0.045	267	-0.150	210	-0.333		
281	-0.034	273	-0.117	211	-0.328		
285	-0.023	284	-0.053	211	-0.328		
290	-0.009	293	0.000	212	-0.323		
293	0.000	302	0.052	214	-0.314		
294	0.003			216	-0.306		
299	0.017	CURVE 3*,‡		220	-0.291		
302	0.025			225	-0.273		
		125	-0.768	229	-0.258		
CURVE 2*,‡		130	-0.748	233	-0.243		
		133	-0.735	238	-0.225		
123	-0.774	137	-0.718	241	-0.214		
128	-0.756	140	-0.706	244	-0.203		
133	-0.738	142	-0.697	249	-0.185		
136	-0.727	145	-0.684	251	-0.177		
142	-0.705	147	-0.675	253	-0.169		
152	-0.669	150	-0.662	261	-0.136		
157	-0.651	152	-0.653	268	-0.106		
163	-0.629	154	-0.643	274	-0.081		
172	-0.596	158	-0.624	279	-0.059		
178	-0.574	161	-0.610	285	-0.034		
183	-0.556	165	-0.591	291	-0.009		

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 198. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POTASSIUM TRIHYDROGEN SELENITE $KH_3(SeO_3)_2$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1*,‡	
123	4.4
127	3.6
139	5.2
146	3.2
183	-7.5
186	-8.0
187	-10.0
190	-10.0
192	-11.8
194	-12.5
198	-15.2
200	-16.2
202	-17.9
203	-19.8
206	-24.5
207	-22.4
208	-25.5
210	-30.8
212	28.1
217	21.9
218	23.9
221	21.7
223	22.0
225	22.0
227	21.4
230	22.0
233	22.5
236	22.7
239	22.3
242	22.0
245	22.0
248	22.8
250	23.0
253	23.8
256	24.8
259	25.9
262	26.5
265	27.0
269	227.1
272	27.1
277	27.4
281	27.4
285	27.4
290	29.5

T	α
CURVE 1 (cont.)*,‡	
293	27.9
294	28.1
299	28.1
302	28.6
CURVE 2*,‡	
123	35.5
128	35.5
133	35.5
136	37.3
142	36.8
152	35.5
157	36.5
163	35.9
172	37.1
178	36.1
183	35.6
183	37.5
188	39.0
193	38.1
198	38.3
201	41.5
203	45.0
207	45.7
209	52.1
211	55.8
213	53.9
214	52.3
216	50.2
218	49.3
223	47.9
228	46.5
233	47.9
238	51.1
240	50.4
243	51.9
253	54.9
258	54.9
263	56.5
267	54.7
273	57.8
284	58.7
293	58.2
302	57.5

T	α
CURVE 3*,‡	
125	40.0
130	41.4
133	41.7
137	41.7
140	42.0
142	43.8
145	44.0
147	44.0
150	45.7
152	46.1
154	48.2
158	47.5
161	47.8
165	48.5
169	50.3
173	51.8
175	53.7
178	53.1
181	53.4
184	54.7
187	56.6
190	57.4
193	58.2
195	59.7
198	61.0
200	62.4
202	63.3
203	63.3
203	64.9
205	66.2
206	67.6
206	66.6
208	66.3
208	67.8
209	69.9
209	68.9
210	56.7
211	55.5
211	51.2
212	45.7
214	39.9
216	37.6
220	37.1
225	38.0

T	α
CURVE 3 (cont.)*,‡	
229	36.5
233	36.5
238	35.6
241	36.6
244	36.6
249	37.3
251	38.8
253	41.2
261	42.3
268	42.2
274	42.7
279	42.7
285	42.1
291	42.6
293	43.1
295	42.5
298	42.5

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 199. THERMAL LINEAR EXPANSION OF SODIUM TRIDEUTERIUM SELENITE $NaD_3(SeO_3)_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	982	Miki, H. and Makita, Y.	1970	X	178-296		Single crystal specimen grown from D_2O solution of one mole Na_2CO_3 and four moles of SeO_2; purity of D_2O is 99.75%; transition point between phases I and II at 270.5 K; lattice parameter measured along a-axis; 10.286 Å reported at 178 K; 10.340 Å at 293 K; coefficient of linear thermal expansion also reported.
2*	982	Miki, H. and Makita, Y.	1970	X	178-296		The above specimen; lattice parameter measured along b-axis; 4.810 Å reported at 178 K, 4.039 Å at 293 K; coefficient of linear thermal expansion also reported.
3*	982	Miki, H. and Makita, Y.	1970	X	178-298		The above specimen; lattice parameter measured along c-axis; 5.694 Å reported at 178 K; 5.851 Å at 293 K; coefficient of linear thermal expansion also reported.

* No figure given.

DATA TABLE 199. THERMAL LINEAR EXPANSION OF SODIUM TRIDEUTERIUM SELENITE $NaD_3(SeO_3)_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 1 (cont.)*		CURVE 2 (cont.)*		CURVE 3*		CURVE 3 (cont.)*	
178	-0.522	268	-0.058	221	-0.219	178	-2.683	288	-0.017
187	-0.493	270	-0.048	232	-0.178	187	-2.564	293	0.000
197	-0.464	275	-0.039	245	-0.074	201	-2.256	298	0.034
201	-0.445	281	-0.029	253	-0.033	213	-2.119		
208	-0.435	287	-0.010	263	0.023	229	-1.863		
219	-0.387	293	0.000	266	0.006	239	-1.658		
229	-0.329	296	0.010	267	-0.021	253	-1.367		
239	-0.300			267	-0.240	263	-1.196		
248	-0.242	CURVE 2*		269	-0.219	265	-1.094		
256	-0.203			275	-0.211	266	-0.974		
262	-0.203	178	-0.597	273	-0.178	267	-0.718		
264	-0.145	187	-0.521	279	-0.130	269	-0.359		
266	-0.126	197	-0.430	284	-0.087	269	-0.222		
267	-0.097	203	-0.384	293	0.000	272	-0.171		
267	-0.068	214	-0.283	296	0.033	278	-0.120		

DATA TABLE 199. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM TRIDEUTERIUM SELENITE $NaD_3(SeO_3)_2$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α
CURVE 1*		CURVE 3*	
93	23	93	1.5
123	25	123	1.5
173	30	173	3
223	36	223	4
273	27	273	19
293	22	293	19
CURVE 2*			
93	50		
123	60		
173	74		
223	83		
273	103		
293	103		

* No figure given.

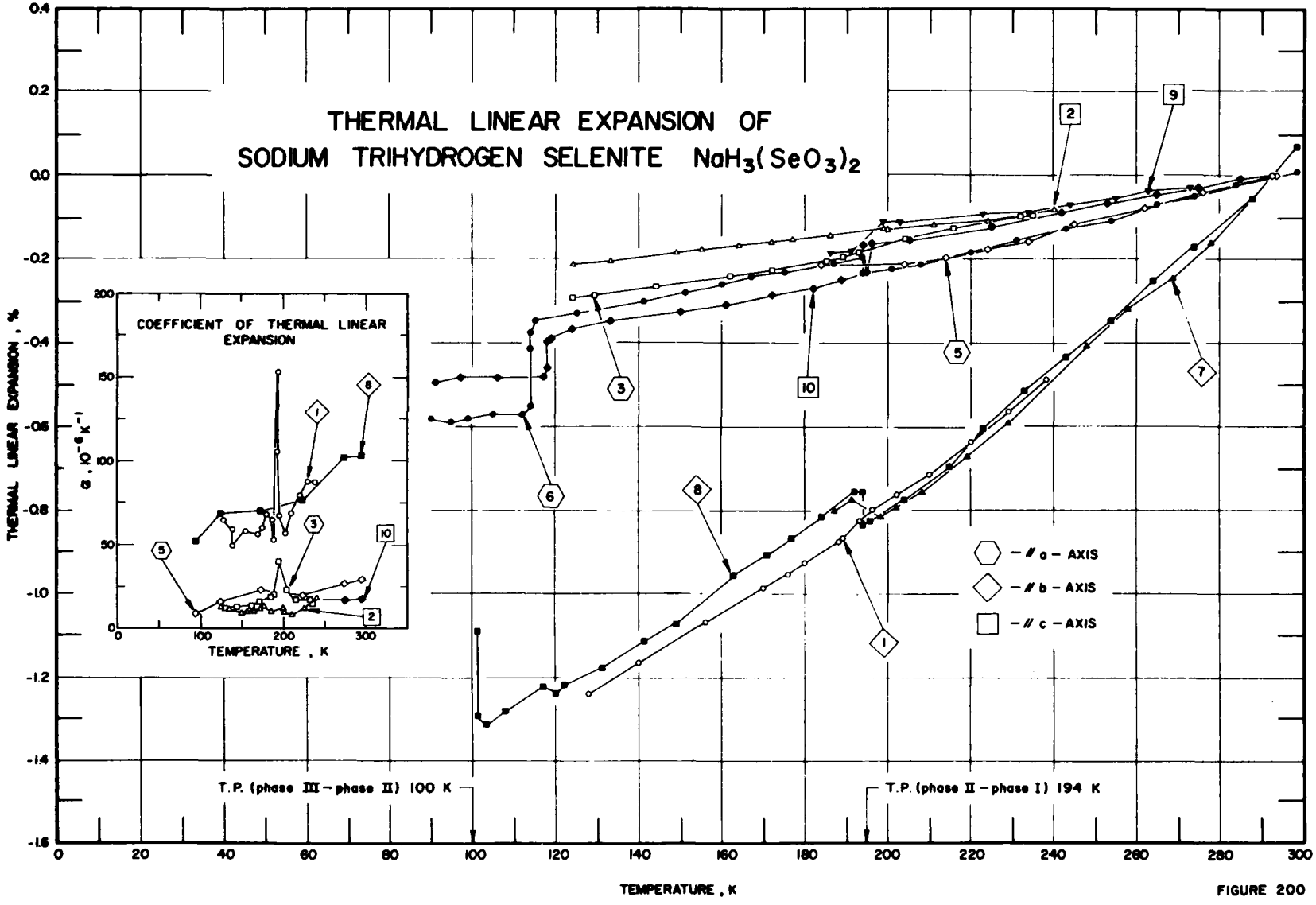

THERMAL LINEAR EXPANSION OF
SODIUM TRIHYDROGEN SELENITE $NaH_3(SeO_3)_2$
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10^{-6} K^{-1}
TEMPERATURE , K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
T.P. (phase III – phase II) 100 K
T.P. (phase II – phase I) 194 K
– // a – AXIS
– // b – AXIS
– // c – AXIS

FIGURE 200

SPECIFICATION TABLE 200. THERMAL LINEAR EXPANSION OF SODIUM TRIHYDROGEN SELENATE $NaH_3(SeO_3)_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	984, 983	Devanarayanan, S. and Narayanan, P.S.	1968	I	128-238		Single crystal 3 x 2 x 1.5 cm, clear, transparent, and flawless, grown by slow evaporation of aqueous solution of Na_2CO_3 and SeO_2 in stoichiometric molar ratio; expansion through ferroelectric transition measured along b-axis of crystal; temperature of transition found to be between 151 K and 152 K; reported error ±2%.
2	984, 983	Devanarayanan, S. and Narayanan, P.S.	1968	I	124-240		The above specimen; expansion measured along z-axis parallel to crystallographic c-axis.
3	984, 983	Devanarayanan, S. and Narayanan, P.S.	1968	I	124-235		The above specimen; expansion measured along x-axis perpendicular to c-axis in (010) plane.
4*	984, 983	Devanarayanan, S. and Narayanan, P.S.	1968	I	140-252		The above specimen in W-direction which lies in (010) plane inclined to c-axis by 151°43'.
5	982	Miki, H. and Makita, Y.	1970	X	184-294		Two phase transitions known at 194 K and near 100 K with three successive phase I, II, and III; phase I (above 194 K) is paraelectric, and phase II (between 194 K and about 100 K) and phase III (below about 100 K) are ferroelectric; single crystal specimen; grown from H_2O solution of one mole Na_2CO_3 and four moles SeO_2; lattice parameter measured along a-axis; 10.338 Å reported at 298 K.
6	982	Miki, H. and Makita, Y.	1970	L	90-299		The above specimen except expansion measured by dilatometer along a-axis; 10.276 Å reported at 90 K; 10.336 Å reported at 293 K.
7	982	Miki, H. and Makita, Y.	1970	X	187-293		The above specimen; expansion measured by x-ray diffractometer along b-axis; 4.840 Å reported at 298 K; 4.797 Å at 187 K.
8	982	Miki, H. and Makita, Y.	1970	L	101-299		The above specimen; expansion measured by dilatometer along b-axis; 4.783 Å reported at 101 K; 4.840 Å reported at 293 K; coefficient of linear thermal expansion also reported.
9	982	Miki, H. and Makita, Y.	1970	X	186-299		The above specimen; expansion measured by x-ray diffractometer along c-axis; 5.775 Å reported at 298 K.
10	982	Miki, H. and Makita, Y.	1970	L	91-293		The above specimen; expansion measured by dilatometer along c-axis; 5.746 Å at 91 K; 5.774 Å at 293 K; coefficient of linear thermal expansion also reported.

* Not shown in figure.

DATA TABLE 200. THERMAL LINEAR EXPANSION OF SODIUM TRIHYDROGEN SELENATE $NaH_3(SeO_3)_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
128	-1.235
140	-1.161
156	-1.066
170	-0.985
176	-0.950
180	-0.925
188	-0.872
189	-0.866
193	-0.824
193	-0.824*
196	-0.799
202	-0.761
210	-0.711
220	-0.637
229	-0.562
238	-0.483
CURVE 2	
124	-0.213
133	-0.202
149	-0.185
155	-0.179
164	-0.169
172	-0.160
177	-0.154
186	-0.143
199	-0.129
200	-0.128
211	-0.118
224	-0.105
240	-0.080
CURVE 3	
124	-0.291
129	-0.285
144	-0.265
162	-0.241
172	-0.227
185	-0.204
189	-0.196
193	-0.183
204	-0.149
216	-0.124
232	-0.097
235	-0.093
CURVE 4*	
140	-0.155
144	-0.164
154	-0.193
161	-0.215
167	-0.231
179	-0.243
190	-0.216
191	-0.210
196	-0.177
203	-0.160
212	-0.170
222	-0.162
224	-0.159
230	-0.147
252	-0.096
CURVE 5	
184	-0.213
204	-0.213
214	-0.193
224	-0.174
234	-0.155
245	-0.116
262	-0.077
276	-0.039
293	0.000
294	0.000
CURVE 6	
90	-0.580
95	-0.590
99	-0.580
105	-0.571
112	-0.571
114	-0.551
114	-0.416
114	-0.377
115	-0.348
125	-0.329
141	-0.300
151	-0.281
160	-0.261
167	-0.242
175	-0.232
187	-0.213
191	-0.203*
194	-0.193
194	-0.232
201	-0.223
208	-0.213
220	-0.184
231	-0.155
243	-0.126
254	-0.106
265	-0.068
274	-0.048
284	-0.019
293	0.000*
299	0.010
CURVE 7	
187	-0.800
191	-0.771
198	-0.817
202	-0.790
208	-0.753
219	-0.668
229	-0.591
248	-0.403
258	-0.318
269	-0.242
278	-0.159
293	0.000*
CURVE 8	
101	-1.088
101	-1.288
103	-1.307
108	-1.278
117	-1.220
120	-1.237
122	-1.216
131	-1.173
141	-1.109
149	-1.071
163	-0.955
171	-0.902
177	-0.864
184	-0.815
192	-0.757
194	-0.757
194	-0.757*
194	-0.836
196	-0.825
204	-0.776
215	-0.693
223	-0.602
233	-0.511
243	-0.432
254	-0.345
264	-0.250
274	-0.168
288	-0.050
293	0.000*
299	0.072
CURVE 9	
186	-0.187
191	-0.182
199	-0.115
203	-0.111
223	-0.091
234	-0.087
244	-0.070
255	-0.053
263	-0.037
273	-0.029
293	0.000*
299	0.007*
CURVE 10	
91	-0.492
97	-0.480
106	-0.480
117	-0.480
118	-0.459
118	-0.397
119	-0.390
124	-0.367
133	-0.348
150	-0.326
161	-0.307
172	-0.284
182	-0.270
189	-0.249
194	-0.229*
194	-0.163
195	-0.229
196	-0.163
205	-0.151
225	-0.121
232	-0.095*
242	-0.085
253	-0.064
265	-0.042
275	-0.029
285	-0.007
293	0.000*

* Not shown in figure.

DATA TABLE 200. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM TRIHYDROGEN SELENATE $NaH_3(SeO_3)_2$

[Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\ K^{-1}$]

T	α
CURVE 1	
128	64.8
140	59.2
156	58.7
170	56.7
176	60.1
180	68.1
188	64.9
189	53.1
193	153.0
193	105.9
196	67.2
202	56.7
210	68.8
220	79.6
229	87.5
238	87.5
CURVE 2	
124	13.09
133	11.76
149	9.60
155	10.08
164	10.70
172	12.11
177	13.35
186	10.23
199	11.53
200	10.23
211	8.43
224	11.79
240	18.46
CURVE 3	
124	11.9*
129	12.5
144	13.0
162	13.8
172	15.8
185	19.4
189	20.7
193	39.9
204	23.4
216	17.4
232	16.2
235	15.6
CURVE 4*	
140	-18.2
144	-26.3
154	-30.6
161	-33.7
167	-20.4
179	11.2
190	48.0
191	64.9
196	69.4
203	-22.9
212	11.1
222	14.6
224	18.8
230	20.4
252	26.2
CURVE 5	
93	9
123	16
173	23
223	20
273	27
293	30
CURVE 8	
93	52
123	69
173	70
223	76
273	102
193	103
CURVE 10	
93	9*
123	17*
173	21*
223	17*
273	17
293	18

* Not shown in figure.

SPECIFICATION TABLE 201. THERMAL LINEAR EXPANSION OF ALUMINUM SILICATES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	307	McKinstry, H.A.	1949		293-1273	Al_2SiO_5 ($Al_2O_3 \cdot SiO_2$)	Aluminum silicate; specimen prepared from C.P. grade Al_2O_3 and silicic acid; wet ground in ball mill, dried, calcined 5 hr at 1373 K; ground and pressed into pellet with small amount Nethocel-Carbowax binder; fired 2 hr at 1973 K; data from smoothed curve.
2*	307	McKinstry, H.A.	1949		293-1273	Al_4SiO_8 ($2Al_2O_3 \cdot SiO_2$)	Aluminum silicate; specimen prepared from C.P. grade Al_2O_3 and silicic acid; wet ground in ball mill, dried, calcined 5 hr at 1373 K; ground and pressed into pellet with small amount Nethocel-Carbowax binder; fired 2 hr at 1973 K; data from smoothed curve.
3*	307	McKinstry, H.A.	1949		293-1273	$Al_6Si_2O_{13}$ ($3Al_2O_3 \cdot 2SiO_2$)	Aluminum silicate; specimen prepared from C.P. grade Al_2O_3 and silicic acid; wet ball milled, dried, calcined 5 hr at 1373 K; ground and pressed into pellet with small amount of Nethocel-Carbowax binder; fired 2 hr at 1973 K; data from smoothed curve.
4*	730	Mazdiyasni, K.S.	1972	X	293-1688	$Al_6Si_2O_{13}$ ($3Al_2O_3 \cdot 2SiO_2$)	Aluminum silicate; sample size 1 x 0.125 x 0.125 in. obtained by vacuum-hot-pressing of high-purity submicron mixed oxide powders; hot-pressing conditions were 5 Kpsi and 1500 C for 30 min; emission spectrographic analysis: Cu, 20 ppm; Cr, 10 ppm; Ti, 10 ppm; Cd, 30 ppm; Co, 30 ppm; Zn, 30 ppm; Na, 300 ppm; expansion measured with increasing temperature.
5*	730	Mazdiyasni, K.S.	1972	X	1649-293	$Al_6Si_2O_{13}$ ($3Al_2O_3 \cdot 2SiO_2$)	Aluminum silicate; the above specimen; expansion measured with decreasing temperature.

* No figure given.

DATA TABLE 201. THERMAL LINEAR EXPANSION OF ALUMINUM SILICATES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
373	0.018
473	0.054
573	0.100
673	0.149
773	0.199
873	0.250
973	0.304
1073	0.359
1173	0.413
1273	0.462
CURVE 2*	
293	0.000
373	0.018
473	0.054
573	0.100
673	0.149
773	0.199
873	0.253
973	0.311
1073	0.371
1173	0.429
1273	0.487
CURVE 3*	
293	0.000
373	0.021
473	0.059
573	0.109
673	0.161
773	0.214
873	0.270
973	0.327
1073	0.387
1173	0.441
1273	0.490
CURVE 4*	
293	0.000
479	0.054
513	0.050
542	0.057
648	0.104
747	0.140
850	0.212
973	0.285
1112	0.367
1233	0.437
1355	0.543
1460	0.539
1688	0.736
CURVE 5*	
1649	0.831
1568	0.747
1543	0.713
1442	0.595
1311	0.581
1236	0.531
1114	0.422
1035	0.373
924	0.314
827	0.247
725	0.247
676	0.211
597	0.191
567	0.137
293	0.000

* No figure given.

SPECIFICATION TABLE 202. THERMAL LINEAR EXPANSION OF CALCIUM SILICATES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	154	Rigby, G.R. and Green, A.T.	1942	L	373-1473	$CaSiO_3$ Wollastonite ($CaO \cdot SiO_2$)	Calcium metasilicate; 51.72 SiO_2, 48.28 CaO; synthetically specimen; prepared by heating mixture of lime and flint to 1380 C in stages using 2% calcium borate as mineralizer; mixture pulverized, bonded with gum and reheated to 1300 C; α-phase; zero-point correction 0.075%.
2*	154	Rigby, G.R. and Green, A.T.	1942	L	373-1473	Ca_2SiO_4 β-calcium orthosilicate ($2CaO \cdot SiO_2$)	Calcium orthosilicate; 65.12 CaO, 34.88 SiO_2; lime and calcined flint together with 2% of calcium borate mixed; specimen moulded by bonding with gum; fired to 1500 C for 1 hr, rebonded with gum and refired at 1475 C for 1 hr; zero-point correction 0.102%.
3*	308	Miyabe, H. and Roy, D.M.	1964	X	299-1665	Ca_3SiO_5 ($3CaO \cdot SiO_2$)	Calcium silicate; reagent-grade calcium carbonate (>0.01 Mg and Ba, 0.006 Al, 0.001 Fe) and silica (<0.001 Na and K, <0.005 heavy metals) mixed in 3:1 molar ratio of CaO and SiO_2 in automatic agate mortar; heated to 1000 C for 24 hr, heated to 1500 C for 12 hr, and quenched in crucible embedded in ice; high-purity specimen selected, free from admixed Ca_2SiO_4, CaO, $CaCO_3$ as observed microscopically and by x-ray diffraction; three principal crystallographic transformations, α-tri clinic-β-triclinic in the range 550 to 700 C, β-triclinic-monoclinic at 910 ± 10 C and monoclinic-trigonal at 970 ± 10 C; heating rate 5 C per min; expansion measured along a-axis.
4*	308	Miyabe, H. and Roy, D.M.	1964	X	299-1213	Ca_3SiO_5 ($3CaO \cdot SiO_2$)	Calcium silicate; the above specimen; expansion measured along b-axis.
5*	308	Miyabe, H. and Roy, D.M.	1964	X	300-1666	Ca_3SiO_5 ($3CaO \cdot SiO_2$)	Calcium silicate; the above specimen; expansion measured along c-axis.
6*	154	Rigby, G.R. and Green, A.T.	1942	L	373-1473	Ca_3SiO_5 Tricalcium Silicate ($3CaO \cdot SiO_2$)	Calcium silicate; 73.68 CaO, 26.32 SiO_2; lime, silica and 2.0% of calcium borate as a mineralizing agent heated together; 2.0% of calcium fluoride with flint to take out excess lime; bar fired twice for at 1600 C for 2 hr.
7*	154	Rigby, G.R. and Green, A.T.	1942	L	373-1473	$Ca_3Si_2O_7$ Tricalcium disilicate ($3CaO \cdot 2SiO_2$)	Calcium silicate; 58.33 CaO, 41.67 SiO_2; lime and silica mixed together and calcined at 1300 C, then melted in carbon crucible; heated in Hirsch furnace; zero-point correction 0.096%.

* No figure given.

DATA TABLE 202. THERMAL LINEAR EXPANSION OF CALCIUM SILICATES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
373	0.075
473	0.169
573	0.267
673	0.368
773	0.473
873	0.583
973	0.698
1073	0.835
1173	0.967
1273	1.090
1373	1.224
1473	1.339

CURVE 2*

T	$\Delta L/L_0$
373	0.102
473	0.230
573	0.359
673	0.489
773	0.637
873	0.797
973	0.980
1073	1.132
1173	1.275
1273	1.413
1373	1.575
1473	1.743

CURVE 3*

T	$\Delta L/L_0$
299	0.006
524	0.219
670	0.219
773	0.793
871	0.850

T	a(Å)
923	12.359
974	12.313
1024	12.323
1069	12.329
1120	12.341
1174	12.356
1191	12.365

CURVE 3 (cont.)*

T	a(Å)
1211	12.363
1231	12.364
1233	7.1255
1251	7.1341
1272	7.1341
1321	7.1357
1373	7.1381
1470	7.1478
1571	7.1545
1623	7.1586
1665	7.1633

CURVE 4*

T	$\Delta L/L_0$
299	0.005
523	0.178
676	0.283
775	0.445
876	0.917
919	0.951

T	b(Å)
926	7.1432
972	7.1103
1024	7.1103
1071	7.1098
1123	7.1098
1139	7.1104
1173	7.1125
1193	7.1220
1213	7.1271

CURVE 5*

T	$\Delta L/L_0$
300	0.007
524	0.222
673	0.381
776	1.222
874	1.114
925	1.106

CURVE 5 (cont.)*

T	c(Å)
879	2.5563
925	2.5404
974	2.5312
1023	2.5337
1071	2.5424
1122	2.5446
1174	2.5436
1190	2.5464
1213	2.5499
1236	2.5479
1254	2.5503
1273	2.5508
1322	2.5555
1371	2.5594
1470	2.5649
1572	2.5715
1624	2.5767
1666	2.5789

CURVE 6*

T	$\Delta L/L_0$
373	0.076
473	0.171
573	0.274
673	0.367
773	0.507
873	0.639
973	0.776
1073	0.917
1173	1.065
1273	1.240
1373	1.356
1473	1.492

CURVE 7*

T	$\Delta L/L_0$
373	0.096
473	0.216
573	0.337
673	0.464
773	0.591
873	0.727
973	0.870

CURVE 7 (cont.)*

T	$\Delta L/L_0$
1073	1.001
1173	1.148
1273	1.291
1373	1.469
1473	1.684

* No figure given.

SPECIFICATION TABLE 203. THERMAL LINEAR EXPANSION OF CALCIUM DIALUMINUM ORTHOSILICATE $CaAl_2(SiO_4)_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	154	Rigby, G.R. and Green, A.T.	1942	L	373-1473	Anorthite $CaO \cdot Al_2O_3 \cdot 2SiO_2$	43.19 SiO_2, 36.65 Al_2O_3, 20.16 MgO; specimen prepared from mixture of China clay, hydrated alumina, lime and 2.0% calcium borate; heated to 1,350 C; pulverized, melted in carbon crucible, heated in Hirsch furnace in coal gas atmosphere; zero-point correction 0.036%.
2*	18	Floyd, J.R.	1964		293-1273	Calcium feldspar $CaO \cdot Al_2O_3 \cdot 2SiO_4$	Specimen prepared from calcined alumina, $CaCO_3$, and -375 mesh SiO_2 wet milled in 3000 g batches for 24 hr with 4500 g of 1 in. diameter alumina balls in 5.5 qt. alumina mills, dried to 473 K, formed into pressing granules using organic binder, dry pressed, fired to 1923 K at average heating rate of 373 K per hr; soaked 3 hr, and cooled at average rate of about 373 K per hr; data from smoothed curve.

DATA TABLE 203. THERMAL LINEAR EXPANSION OF CALCIUM DIALUMINUM ORTHOSILICATE $CaAl_2(SiO_4)_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*	
373	0.036	373	0.024
473	0.081	473	0.065
573	0.128	573	0.106
673	0.174	673	0.149
773	0.226	773	0.193
873	0.285	873	0.244
973	0.344	973	0.300
1073	0.438	1073	0.376
1173	0.566	1173	0.453
1273	0.613	1273	0.539
1373	0.647		
1473	0.675		

* No figure given.

SPECIFICATION TABLE 204. THERMAL LINEAR EXPANSION OF CALCIUM MAGNESIUM SILICATES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	154	Rigby, G.R. and Green, A.T.	1942	L	373-1473	$CaMgSiO_4$ Monticellite $CaO \cdot MgO \cdot SiO_2$	Calcium magnesium orthosilicate; specimen prepared from dolomite having equimolecular proportion of lime, magnesia and silica; fused with gum; sintered at 1300 C; zero-point correction 0.087%.
2*	154	Rigby, G.R. and Green, A.T.	1942	L	373-1473	$CaMg(SiO_3)_2$ Diopside $CaO \cdot MgO \cdot 2SiO_2$	Calcium magnesium metasilicate; specimen prepared from dolomite having equimolecular proportions of lime, magnesia, and silica; fused with gum; sintered at 1300 C; zero-point correction 0.054%.
3*	128	Wisely, H.R.	1962	L	373-973	$Ca_2MgSi_2O_7$ Akermenito $2CaO \cdot MgO \cdot 2SiO_2$	Dicalcium magnesium silicate; bar specimen; 0.25 x 0.75 x 1 in.; pressed under pressure 26,000 psi, sintered 2 hr at 1350 C.
4*	154	Rigby, G.R. and Green, A.T.	1942	L	373-1473	$Ca_2MgSi_2O_7$ Akermenito $2CaO \cdot MgO \cdot 2SiO_2$	Dicalcium magnesium silicate; raw material crushed, packed into graphite mould, melted in molybdenum wire-wound furnace; zero-point correction 0.070%.
5*	154	Rigby, G.R. and Green, A.T.	1942	L	393-1473	$Ca_3Mg(SiO_4)_2$ Merwinite	Tricalcium magnesium orthosilicate; 51.18 CaO, 56.55 SiO_2, 12.26 MgO; specimen prepared from mixture of dolonite, lime and flint; heated at 1450 C for 3 hr; zero-point correction 0.078%.

DATA TABLE 204. THERMAL LINEAR EXPANSION OF CALCIUM MAGNESIUM SILICATES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
373	0.087
473	0.196
573	0.308
673	0.432
773	0.559
873	0.692
973	0.819
1073	0.944
1173	1.074
1273	1.211
1373	1.354
1473	1.499

CURVE 2*

T	$\Delta L/L_0$
373	0.054
473	0.122
573	0.190
673	0.270
773	0.349
873	0.439
973	0.526
1073	0.614
1173	0.701
1273	0.801
1373	0.914
1473	1.027

CURVE 3*

T	$\Delta L/L_0$
373	0.077
673	0.365
973	0.671

CURVE 4*

T	$\Delta L/L_0$
373	0.070
473	0.158
573	0.242
673	0.358
773	0.464
873	0.569
973	0.663
1073	0.771
1173	0.890
1273	1.008
1373	1.133
1473	1.267

CURVE 5*

T	$\Delta L/L_0$
373	0.078
473	0.175
573	0.285
673	0.409
773	0.558
873	0.691
973	0.824
1073	0.960
1173	1.122
1273	1.277
1373	1.426
1473	1.549

* No figure given.

SPECIFICATION TABLE 205. THERMAL LINEAR EXPANSION OF CESIUM ALUMINUM METASILICATE $CsAl(SiO_3)_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	309	Taylor, D. and Henderson, C.M.B.	1968	X	293-1038	Pollucite	Synthetic Cs-Leucite; prepared as gel from K_2CO_3 and Al powder; dissolved in nitric acid; ludox tetraethyl orthosilicate added; crystallized 3 to 6 days in platinum capsule at 1373 to 1473 K; cubic structure at 25 C.
2*	1051	Richerson, D.W.	1969	L	329-1230	Pollucite	Samples prepared from pure, well-crystallized powders which were mixed with Methocel-Carbowax binder and pressed at 7000 psi in a 10 cm x 1 cm diameter homogeneous bars (without laminations) were sintered at various temperatures above 1020 C.
3*	1051	Richerson, D.W.	1969	L	314-1272	Pollucite	Similar to the above specimen except Li-exchange sample (0.95 wt. % Li_2O present).
4*	1051	Richerson, D.W.	1969	L	326-1290	Pollucite	Similar to the above specimen except Na-exchange sample (1.72 wt. % Na_2O present).

DATA TABLE 205. THERMAL LINEAR EXPANSION OF CESIUM ALUMINUM METASILICATE $CsAl(SiO_3)_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
293	0.000
304	0.015
377	0.154
467	0.271
571	0.307
746	0.278
795	0.263
858	0.278
942	0.285
1038	0.307

CURVE 2*

T	$\Delta L/L_0$
329	0.031
351	0.050
378	0.071
430	0.102
512	0.139
583	0.171
635	0.193
683	0.212
732	0.234
780	0.262
830	0.291
877	0.320
930	0.351
940	0.377
1030	0.392
1079	0.410
1130	0.427
1180	0.445
1230	0.463

CURVE 3*

T	$\Delta L/L_0$
314	0.015
337	0.032
377	0.069
482	0.116
534	0.132
581	0.148
635	0.162
680	0.175
733	0.188
779	0.199
829	0.213
875	0.228
926	0.238
975	0.249
1025	0.256
1073	0.264
1126	0.275
1175	0.282
1223	0.291
1272	0.299

CURVE 4*

T	$\Delta L/L_0$
326	0.036
352	0.063
377	0.097
455	0.139
537	0.159
583	0.170
683	0.187
731	0.198
781	0.208
805	0.213
853	0.222
953	0.242
997	0.251
1047	0.260
1097	0.272
1176	0.290
1227	0.304
1290	0.321

* No figure given.

SPECIFICATION TABLE 206. THERMAL LINEAR EXPANSION OF IRON SILICATES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	158	Rigby, G.R., Lovell, H.B., and Green, A.T.	1945	T	373-1273	Fe_2SiO_4 Fayalite ($2FeO \cdot SiO_2$)	Iron orthosilicate; 65.94 FeO, 28.88 SiO_2, 4.09 Fe_2O_3, 0.46 CaO; cylindrical specimen 2 cm diameter, 5 cm long; prepared by fusing appropriate mixture in steel vessels in purified nitrogen atmosphere; specific gravity 4.28.
2*	158	Rigby, G.R., Lovell, H.B., and Green, A.T.	1945	T	373-1273	$FeCaSiO_4$ ($CaFeSiO_4$) orthosilicate ($CaO \cdot FeO \cdot SiO_2$)	Iron calcium orthosilicate; 36.6 FeO, 31.24 SiO_2, 29.51 CaO, 1.6 Fe_2O_3, 0.53 MgO; cylindrical specimen 2 cm diameter 5 cm long; prepared by fusing appropriate mixture in steel vessel in purified nitrogen atmosphere; specific gravity 3.55.
3*	253	Rigby, G.R., Lovell, G.H.B., and Green, A.T.	1946	T	373-1073	$FeCaMg_2(SiO_3)_4$ ($CaO \cdot FeO \cdot 2MgO \cdot 4SiO_2$)	Iron calcium dimagnesium metasilicate; synthetic sintered cylindrical specimen 2 cm diameter, 5 cm long; specific gravity 3.46.
4*	253	Rigby, G.R., Lovell, G.H.B., and Green, A.T.	1946	T	373-1073	$Fe_2CaMg(SiO_4)_2$ ($CaO \cdot MgO \cdot 2FeO \cdot 2SiO_2$)	Diiron calcium magnesium orthosilicate; synthetic sintered cylindrical specimen 2 cm diameter, 5 cm long; specific gravity 3.80.

DATA TABLE 206. THERMAL LINEAR EXPANSION OF IRON SILICATES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
373	0.07
473	0.16
573	0.26
673	0.36
773	0.46
873	0.57
973	0.68
1073	0.78
1173	0.88
1273	0.98
CURVE 2*	
373	0.07
473	0.16
573	0.26
673	0.35
773	0.47
873	0.59
973	0.71
1073	0.85
1173	0.97
1273	1.10
CURVE 3*	
373	0.05
473	0.11
573	0.17
673	0.25
773	0.31
873	0.38
973	0.46
1073	0.54
CURVE 4*	
373	0.08
473	0.18
573	0.28
673	0.39
773	0.51
873	0.64
973	0.76
1073	0.89

* No figure given.

SPECIFICATION TABLE 207. THERMAL LINEAR EXPANSION OF LEAD SILICATES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	310	Argyle, J. F. and Hummel, F. A.	1960		298-947	$PbSiO_3$ ($PbO \cdot SiO_2$)	Lead metasilicate; 78.81 PbO and 21.19 SiO_2; bar specimen prepared from c.p. lead carbonate and silicic acid hand-mixed with acetone for 15 to 20 min, air-dried overnight, calcined at 473 K for 4 hr, fired to 1023 K for 6 hr, cooled, ground, remixed, fired at 1023 K for 24 hr, ground, mixed with Carbowax solution, forced through 20 mesh sieve, pressed into 1 x 1 x 10 cm bar at 1000 psi, and sintered to a relatively dense condition; original length 109.9 mm; heating rate of 393 K per hr; data from smoothed curve.
2*	310	Argyle, J. F. and Hummel, F. A.	1960		298-947	Pb_2SiO_4 ($2PbO \cdot SiO_2$)	Lead orthosilicate; 88.14 PbO and 11.86 SiO_2; specimen prepared from c.p. lead carbonate and silicic acid hand-mixed with acetone for 15 to 20 min, air-dried overnight, calcined at 473 K for 4 hr, fired to 998 K for 6 hr, cooled, ground, remixed, fired at 998 K for 24 hr, ground, mixed with carbowax solution, forced through 20-mesh sieve, pressed into 1 x 1 x 10 cm bars at 1000 psi, and sintered to a relatively dense condition; original length 106.5 mm; heating rate 393 K per hr; data from smoothed curve.
3*	310	Argyle, J. F. and Hummel, F. A.	1960		298-941	Pb_4SiO_6 ($4PbO \cdot SiO_2$)	Lead silicate; 93.71 PbO and 6.29 SiO_2; specimen prepared from c.p. lead carbonate and silicic acid hand-mixed with acetone for 15 to 20 min, air-dried overnight, calcined at 473 K for 4 hr, fired to 973 K for 6 hr, cooled, ground, remixed, fired at 973 K for 36 hr, ground, mixed with carbowax solution, forced through 20-mesh sieve, pressed into 1 x 1 x 10 cm bar at 1000 psi, and sintered to a relatively dense condition; γ-$4PbO \cdot SiO_2$ - β-$4PbO \cdot SiO_2$ phase transformation in temperature range 383-445 K; original length 101 mm; heating rate 393 K per hr; data from smoothed curve.
4*	310	Argyle, J. F. and Hummel, F. A.	1960		298-753	$Pb_5B_2SiO_{10}$ ($5PbO \cdot B_2O_3 \cdot SiO_2$	Lead boron silicate; 89.56 PbO, 5.59 B_2O_3, and 4.85 SiO_2; bar specimen prepared from c.p. lead carbonate, silic acid, and boric acid hand-mixed with acetone for 15 to 20 min, air-dried overnight, calcined at 473 K for 4 hr, fired to 773 K for 6 hr, cooled, ground, remixed, fired at 773 K for 24 hr, ground, mixed with carbowax solution, forced through 20-mesh sieve, pressed into 1 x 1 x 10 cm bar at 1000 psi, and sintered to a relatively dense condition; original length 79.9 mm; heating rate 120 C per hr; data from smoothed curve.

* No figure given.

DATA TABLE 207. THERMAL LINEAR EXPANSION OF LEAD SILICATES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
302	0.000
323	0.012
373	0.040
423	0.077
473	0.117
523	0.164
573	0.206
623	0.256
673	0.302
723	0.351
773	0.402
823	0.456
873	0.510
923	0.556
947	0.571
CURVE 2*	
302	0.000
323	0.022
373	0.071
423	0.130
473	0.194
523	0.266
573	0.331
623	0.404
673	0.476
723	0.556
773	0.634
823	0.725
873	0.831
923	0.976
933	1.000
CURVE 3*	
302	0.000
323	0.017
373	0.058
380	0.066
388	0.066
410	0.036
423	0.031
435	0.037
CURVE 3 (cont.)*	
473	0.077
523	0.153
573	0.226
623	0.300
673	0.375
723	0.458
773	0.543
823	0.634
873	0.718
923	0.796
949	0.822
CURVE 4*	
302	0.000
323	0.046
373	0.111
423	0.172
473	0.229
523	0.308
573	0.366
623	0.432
673	0.501
723	0.569
756	0.590

* No figure given.

SPECIFICATION TABLE 208. THERMAL LINEAR EXPANSION OF LITHIUM SILICATES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	42	Kirchner, H. P., Merz, K. M., and Smyth, H. T.	1959	L	293-963	$Li_2Si_2O_5$	Lithium silicate; specimen 4.395 in. long, 0.437 in. square; prepared by heating Li_2CO_3 and SiO_2 together in platinum crucible over Mlker burner until most of the CO_2 had been driven off; the crucible slowly heated to 1100 C in an electric muffle furnace for 4 hr; the product crushed and then ball-milled for 36 hr; mixed with 15% binder solution, pressed at 5000 psi and then fired at 900 C to form a bar specimen; reported error ±2%.
2*	311	Soga, N.	1964		303-873	Li_4SiO_4	Lithium orthorsilicate; specimen prepared from Fisher-certified reagent grade Li_2CO_3 and SiO_2 (99.9 silica from Wedron Silica Co.); wet mixed under alcohol, heated at 393 K per hr to 1373 K, held at 1373 K for 20 hr, pressed at 5000 psi, and refired at 1373 K for 3 hr, heating rate of 25 C per min.
3*	280	Ikedak, K. and Minagawa, K.	1966	L	293-673	$LiAlSiO_4$ β-Eucryptite $Li_2O \cdot Al_2O_3 \cdot 2SiO_2$	Lithium aluminum orthosilicate; 46.56 SiO_2, 39.50 Al_2O_3, 13.94 Li_2O; specimen prepared from 43.67 aluminum hydroxide, 35.21 silica powder and 21.12 lithium carbonate; no heat-treatment.
4*	280	Ikedak, K. and Minagawa, K.	1966	L	293-673	$LiAlSiO_4$ β-Eucryptite $Li_2O \cdot Al_2O_3 \cdot 2SiO_2$	Lithium aluminum orthosilicate; similar to the above specimen; heat-treated at 800 C for 15 min and cooled in furnace.
5*	280	Ikedak, K. and Minagawa, K.	1966	L	293-673	$LiAlSiO_4$ β-Eucryptite $Li_2O \cdot Al_2O_3 \cdot 2SiO_2$	Lithium aluminum orthosilicate; similar to the above specimen; heat-treated at 1000 C for 15 min and cooled in furnace.
6*	280	Ikedak, K. and Minagawa, K.	1966	L	293-673	$LiAlSiO_4$ β-Eucryptite $Li_2O \cdot Al_2O_3 \cdot 2SiO_2$	Lithium aluminum orthosilicate; similar to the above specimen; no heat-treatment.
7*	280	Ikedak, K. and Minagawa, K.	1966	L	293-673	$LiAlSiO_4$ β-Eucryptite $Li_2O \cdot Al_2O_3 \cdot 2SiO_2$	Lithium aluminum orthosilicate; similar to the above specimen; heat-treated at 1000 C for 20 min and quenched in air atmosphere.
8*	280	Ikedak, K. and Minagawa, K.	1966	L	293-673	$LiAlSiO_4$ β-Eucryptite $Li_2O \cdot Al_2O_3 \cdot 2SiO_2$	Lithium aluminum orthosilicate; similar to the above specimen; heat-treated at 800 C for 2.5 hr and quenched in air atmosphere.
9*	280	Ikedak, K. and Minagawa, K.	1966	L	293-633	$LiAlSiO_4$ β-Eucryptite $Li_2O \cdot Al_2O_3 \cdot 2SiO_2$	Lithium aluminum orthosilicate; similar to the above specimen; except prepared by melting method; no heat-treatment.
10*	280	Ikedak, K. and Minagawa, K.	1966	L	293-600	$LiAlSiO_4$ β-Eucryptite $Li_2O \cdot Al_2O_3 \cdot 2SiO_2$	Lithium aluminum orthosilicate; similar to the above specimen; heat-treated at 800 C for 2.5 hr.

* No figure given.

SPECIFICATION TABLE 208. THERMAL LINEAR EXPANSION OF LITHIUM SILICATES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
11*	280	Ikedak, K. and Minagawa, K.	1966	L	293-673	$LiAlSiO_4$ ($Li_2O \cdot Al_2O_3 \cdot 2SiO_2$)	Lithium aluminum orthosilicate; similar to the above specimen; heat-treated at 1000 C for 20 min and quenched in air atmosphere and heat-treated again at 800 C for 2.5 hr.
12*	280	Ikedak, K. and Minagawa, K.	1966	L	293-673	$LiAlSiO_4$ ($Li_2O \cdot Al_2O_3 \cdot 2SiO_2$)	Lithium aluminum orthosilicate; similar to the above specimen; no heat-treatment.
13*	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	298-1473	$LiAlSiO_4$	Lithium aluminum orthosilicate; specimen fine grain with a cross section 1/2 x 1/2 in. and 7 in. long; the ends sawed at a rake and to a point.

DATA TABLE 208. THERMAL LINEAR EXPANSION OF LITHIUM SILICATES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
293	0.000
363	0.040
433	0.100
508	0.172
551	0.215
683	0.370
723	0.410
793	0.500
873	0.610
963	0.755

CURVE 2*

T	$\Delta L/L_0$
303	0.018
323	0.048
348	0.091
373	0.145
398	0.181
423	0.229
448	0.278
473	0.329
498	0.380
523	0.433
548	0.487
573	0.542
598	0.598
623	0.655
648	0.714

CURVE 2 (cont.)*

T	$\Delta L/L_0$
673	0.774
698	0.834
723	0.897
748	0.961
773	1.025
798	1.092
823	1.162
848	1.236
873	1.310

CURVE 3*

T	$\Delta L/L_0$
293	0.000
323	-0.010
373	-0.031
423	-0.059
473	-0.085
523	-0.112
573	-0.139
623	-0.167
673	-0.192

CURVE 4*

T	$\Delta L/L_0$
293	0.000
323	-0.017
373	-0.043
423	-0.073

CURVE 4 (cont.)*

T	$\Delta L/L_0$
473	-0.102
523	-0.132
573	-0.161
623	-0.192
673	-0.219

CURVE 5*

T	$\Delta L/L_0$
293	0.000
323	-0.014
373	-0.037
423	-0.066
473	-0.093
523	-0.120
573	-0.146
623	-0.174
673	-0.199

CURVE 6*

T	$\Delta L/L_0$
293	0.000
323	-0.008
373	-0.030
423	-0.055
473	-0.086
523	-0.113
573	-0.141
623	-0.169
673	-0.195

CURVE 7*

T	$\Delta L/L_0$
293	0.000
323	-0.013
373	-0.041
423	-0.067
473	-0.095
523	-0.128
573	-0.161
623	-0.192
673	-0.223

CURVE 8*

T	$\Delta L/L_0$
293	0.000
323	-0.013
373	-0.043
423	-0.067
473	-0.099
523	-0.131
573	-0.168
623	-0.203
673	-0.237

CURVE 9*

T	$\Delta L/L_0$
293	0.000
323	-0.014
373	-0.054
423	-0.091

CURVE 9 (cont.)*

T	$\Delta L/L_0$
473	-0.136
523	-0.179
573	-0.234
623	-0.279
633	-0.300

CURVE 10*

T	$\Delta L/L_0$
293	0.000
323	-0.017
373	-0.067
423	-0.111
473	-0.162
523	-0.211
573	-0.269
600	-0.300

CURVE 11*

T	$\Delta L/L_0$
293	0.000
323	-0.015
373	-0.041
423	-0.069
473	-0.094
523	-0.126
573	-0.157
623	-0.191
673	-0.222

CURVE 12*

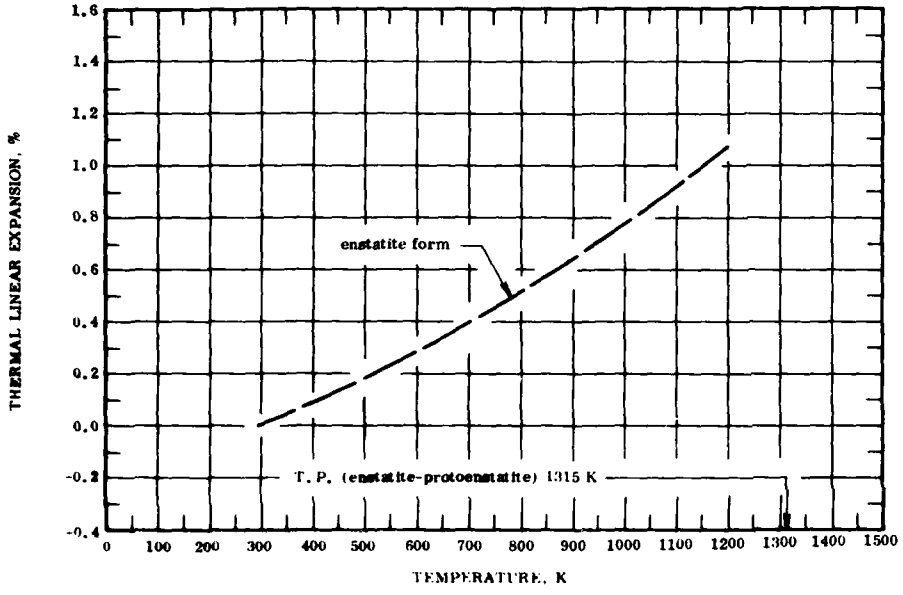
T	$\Delta L/L_0$
293	0.000
323	-0.016
373	-0.040
423	-0.070
473	-0.099
523	-0.130
573	-0.168
623	-0.203
673	-0.235

CURVE 13*

T	$\Delta L/L_0$
298	-0.001
573	-0.081
873	-0.064
1173	-0.053
1473	0.000

* No figure given.

FIGURE AND TABLE NO. 209R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF MAGNESIUM METASILICATE $MgSiO_3$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	8.6
400	0.095	9.2
500	0.189	9.7
600	0.290	10.4
700	0.400	11.2
800	0.514	12.0
900	0.640	12.9
1000	0.773	13.9
1100	0.918	15.0
1200	1.074	16.2

REMARKS

The provisional values for the stable Enstatite form are based on the data reported in Curve 2. The Enstatite form which is a stable low-temperature modification inverts to protoenstatite, the stable high-temperature modification, at 1315 K. These values are considered accurate to within ±1% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.236 + 7.632 \times 10^{-4} T + 1.061 \times 10^{-7} T^2 + 1.398 \times 10^{-10} T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

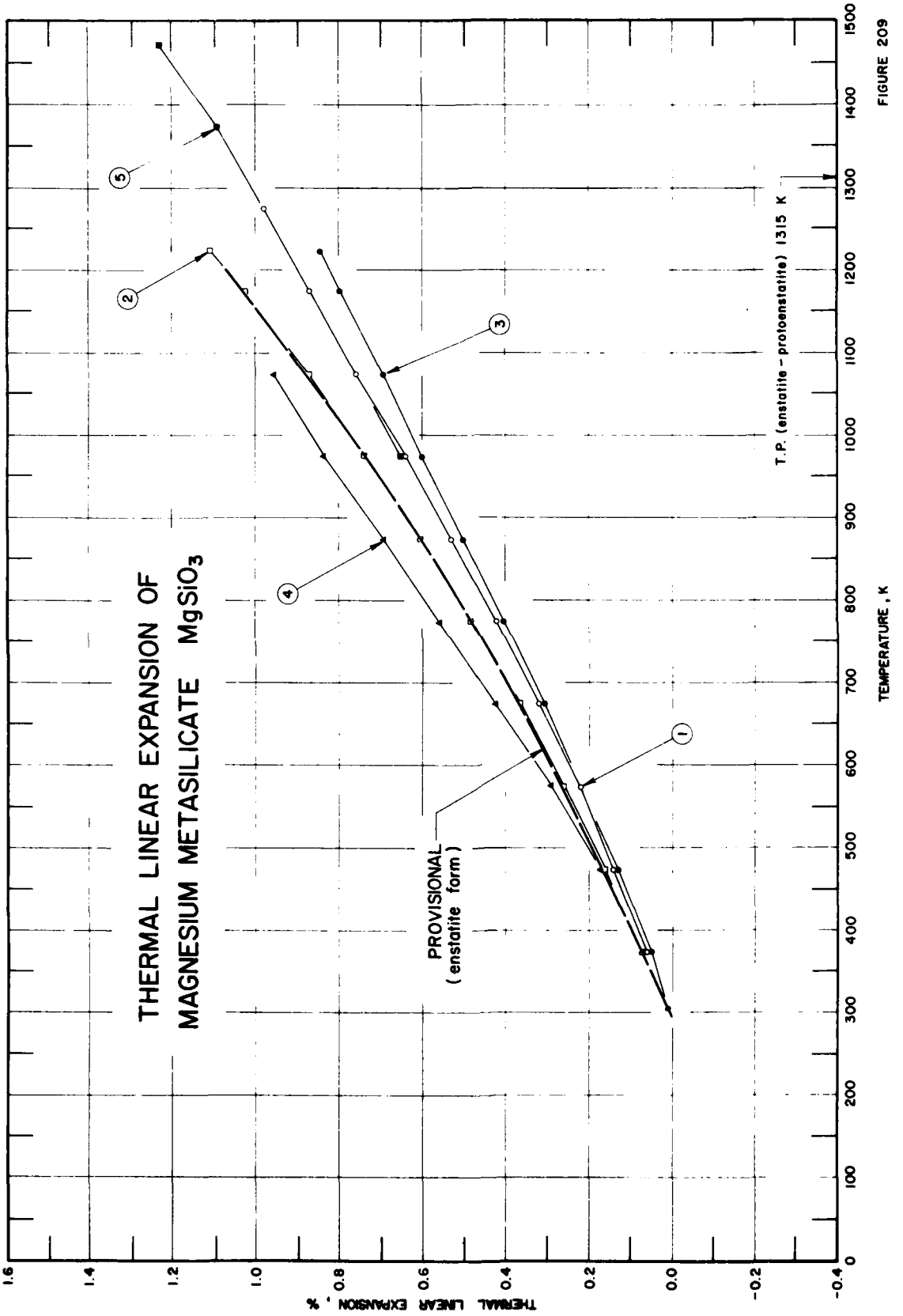

THERMAL LINEAR EXPANSION OF
MAGNESIUM METASILICATE $MgSiO_3$
PROVISIONAL
(enstatite form)
T.P. (enstatite – protoenstatite) 1315 K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1
2
3
4
5

FIGURE 209

SPECIFICATION TABLE 209. THERMAL LINEAR EXPANSION OF MAGNESIUM METASILICATE $MgSiO_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	253	Rigby, G.R., Lovell, G.H.B., and Green, A.T.	1946	T	473-1273	Clinoenstatite $MgO \cdot SiO_2$	Synthetic sintered cylindrical specimen 2 cm diameter, 5 cm long; specific gravity 3.19.
2	313	Sarver, J.F. and Hummel, F.A.	1962		303-1223	Enstatite	Polycrystalline specimen 1 x 1 x 10 cm; prepared from batch materials weighed to 0.1 mg, manually blended in acetone for 15 to 30 min, heated to 1123 K for 24 to 48 hr, remixed by hand for 20 to 30 min, reacted at 1223 K for several hr, machine ground, mixed in acetone for 45 to 60 min, mixed with 5% organic binder, and pressed at about 10,000 psi; enstatite polymorph prepared from $MgO \cdot SiO_2$ mixed with 0.02 mole LiF, fired to 1373 K for a few hr to form dense protoeastatite bar, cooled slowly to 1223 K and held for 2 hr; at room temperature specimen consisted only of enstatite; heating rate 398 K per hr; density 3.21 g cm^{-3}.
3	313	Sarver, J.F. and Hummel, F.A.	1962		303-1221	Protoenstatite	Sample prepared as above; protoenstatite specimen made by stabilizing sample with 0.02 mole $MnSiO_3$ and firing at 1573 K for 24 hr, with 0.02 mole MgF_2 added as numeralizer; heating rate 398 K per hr; density 3.10 g cm^{-3}.
4	313	Sarver, J.F. and Hummel, F.A.	1962		303-1173	Clinoenstatite	Polycrystalline sample prepared as above; clinoenstatite specimen prepared from sample mixed with 0.02 mole LiF, fired at 1373 K for 24 hr to form protoenstatite, transferred while hot to another furnace at 800 C and held at this temperature for 24 hr; at room temperature, bar consisted only of clinoenstatite; density 3.19 g cm^{-3}; heating rate 398 K per hr.
5	86	Rigby, G.R. and Green, A.T.	1941	L	373-1473	Clinoenstatite	Calcined magnesium carbonate added to steatite A ($3MgO \cdot 4SiO_2 \cdot H_2O$) together with 2.0% magnesium fluoride as mineralizer; bar moulded from mix, fired initially to 1000 C, then to 1500 C; bar then powdered, rebonded and fired to 1450 C.

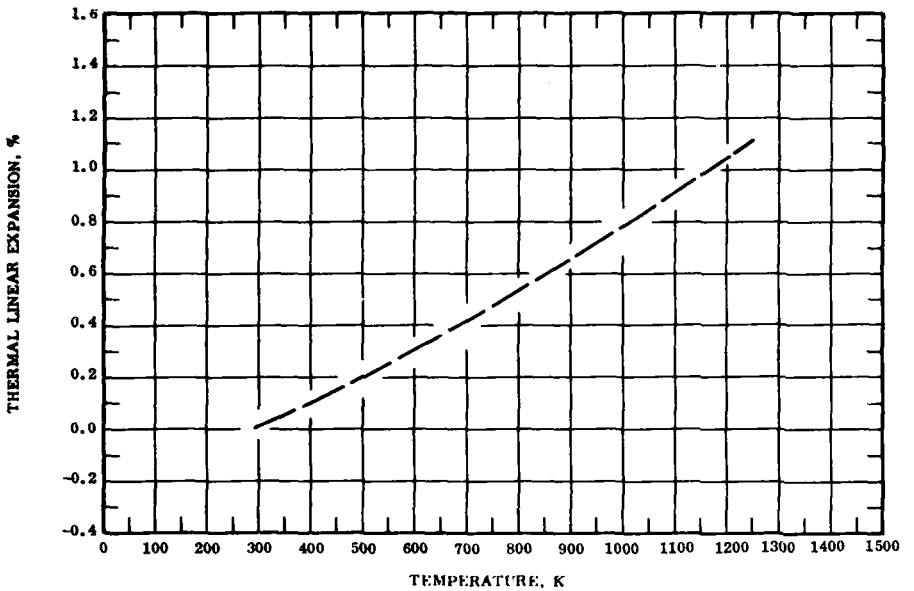
DATA TABLE 209. THERMAL LINEAR EXPANSION OF MAGNESIUM METASILICATE $MgSiO_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3		CURVE 4		CURVE 5		CURVE 5 (cont.)	
373	0.06	303	0.010*	303	0.010	303	0.008*	373	0.062*	1473	1.227
473	0.14	373	0.010	373	0.055	373	0.068*	473	0.140*		
573	0.22	473	0.160	473	0.129	473	0.172	573	0.225*		
673	0.32	573	0.260	573	0.215*	573	0.292	673	0.320*		
773	0.42	673	0.364	673	0.309	673	0.422	773	0.423*		
873	0.53	773	0.482	773	0.405	773	0.558	873	0.535*		
973	0.64	873	0.602	873	0.501	873	0.698	973	0.646		
1073	0.76	973	0.740	973	0.601	973	0.838	1073	0.758*		
1173	0.87	1073	0.878	1073	0.699	1073	0.958	1173	0.867*		
1273	0.98	1173	1.026	1173	0.799	1173	1.052*	1273	0.982*		
		1223	1.110	1221	0.845			1373	1.092		

* Not shown in figure.

FIGURE AND TABLE NO. 210R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF MAGNESIUM ORTHOSILICATE Mg_2SiO_4



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	9.0
400	0.100	9.7
500	0.200	10.3
600	0.305	10.8
700	0.416	11.3
800	0.532	11.8
900	0.653	12.3
1000	0.779	12.8
1100	0.909	13.2
1200	1.043	13.6
1250	1.112	13.8

REMARKS

The provisional values are based on the data for forsterite samples and are considered accurate to within ±7%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.238 + 7.166 \times 10^{-4}\, T + 3.381 \times 10^{-7}\, T^2 - 3.797 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

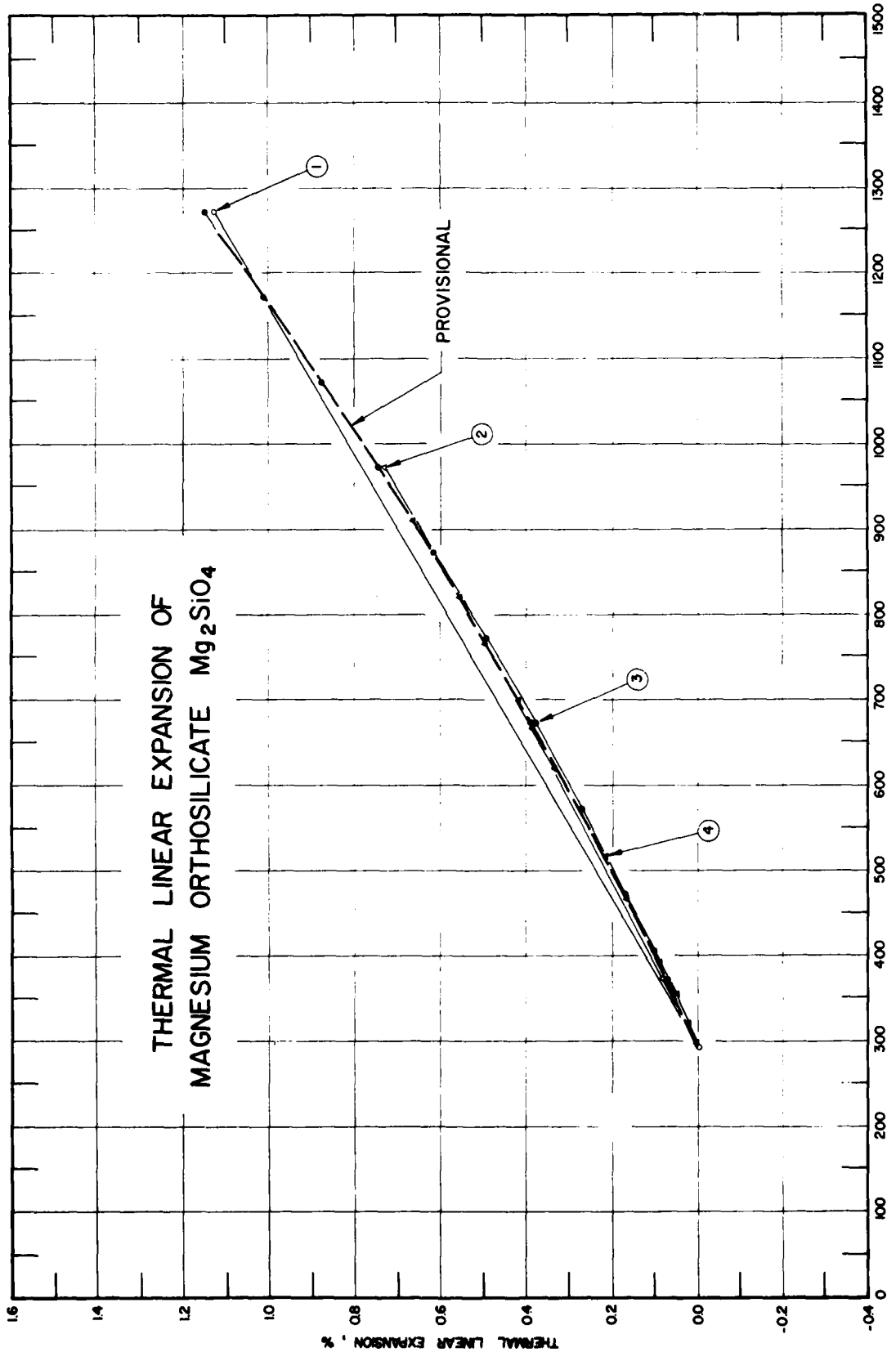

THERMAL LINEAR EXPANSION OF
MAGNESIUM ORTHOSILICATE Mg_2SiO_4
PROVISIONAL
1
2
3
4
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 210

SPECIFICATION TABLE 210. THERMAL LINEAR EXPANSION OF MAGNESIUM ORTHOSILICATE Mg_2SiO_4

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	314	Wen, Pu-Yi, Brown, J.J., and Hummel, F.A.	1964		293, 1273	Sample A7	57.3 MgO and 42.70 SiO_2; specimen prepared from basic magnesium carbonate and silicic acid mixed together, dried, pressed into 1 x 1 x 10 cm bars at 500 psi, and heat treated; heating rate 125 K per hr.
2	128	Wisely, H.R.	1962	L	373-973	Forsterite	Bar specimen, 2 in. by 3/8 in. by 1/4 in. formed under pressure 26,000 psi, sintered 2 hr at 1550 C in air atmosphere.
3	154	Rigby, G.R. and Green, A.T.	1942	L	373-1473	Forsterite $2MgO \cdot SiO_2$ synthetic	57.29 MgO and 42.70 SiO_2; calcined magnesia added to steatite, and 2% magnesium fluoride used as fluxing agent; bar fired to 1000 C, held at 1000 C for 2 hr, then reground, sintered at 1,250 C.
4	312	Soga, N. and Anderson, O.L.	1967	L	298-910	Forsterite	50.6 MgO, 42.3 SiO_2, 4.0 BaO, 2.2 Al_2O_3, 0.5 Fe_2O_3, 0.2 CaO, and 0.1 Na_2O; sintered polycrystalline specimen, 0.375 in. diameter, 5 in. long; supplied by Silk City Industrial Ceramics, Inc.; average particle size 12 to 15 μ.

DATA TABLE 210. THERMAL LINEAR EXPANSION OF MAGNESIUM ORTHOSILICATE Mg_2SiO_4

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
1273	1.127
CURVE 2	
373	0.082
673	0.388
973	0.730

T	$\Delta L/L_0$
CURVE 3	
373	0.075
473	0.169
573	0.270
673	0.378
773	0.495
873	0.617
973	0.745
1073	0.878
1173	1.012
1273	1.149
1373	1.171
1473	1.414

T	$\Delta L/L_0$
CURVE 4‡	
298	0.004
320	0.022
355	0.053
355	0.053*
391	0.087
405	0.101
469	0.166
517	0.216
571	0.275*
621	0.331
667	0.382
700	0.419

T	$\Delta L/L_0$
CURVE 4 (cont.)‡	
768	0.496
820	0.556
910	0.661

DATA TABLE 210. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MAGNESIUM ORTHOSILICATE Mg_2SiO_4

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 4*,‡	
298	8.00
320	8.55
355	8.95
355	9.48
391	9.48
405	10.14
469	10.21
517	10.83
571	11.03
621	11.03
667	11.22
700	11.42
768	11.25
820	11.66
910	11.66

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta l./l_0$.

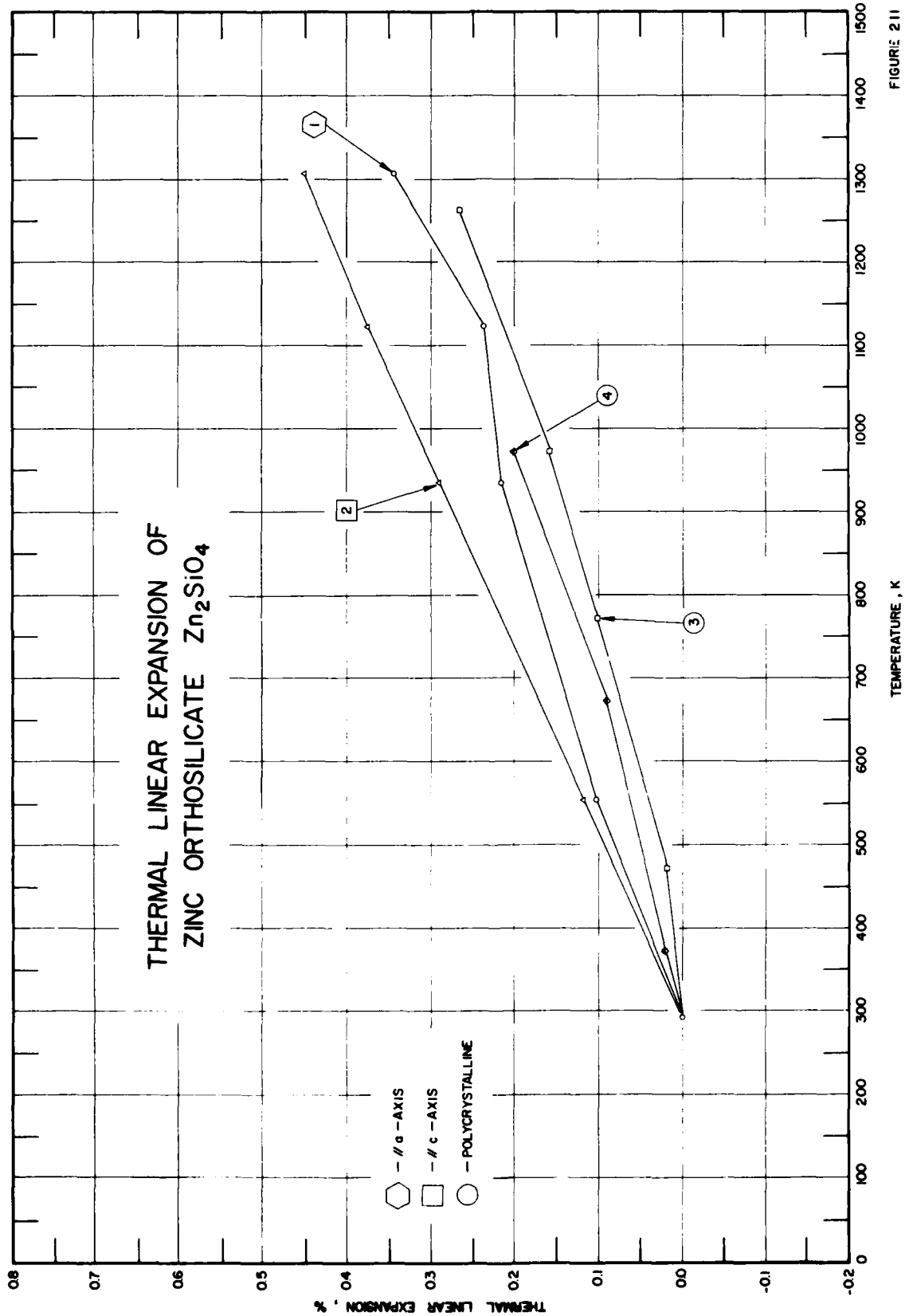

THERMAL LINEAR EXPANSION OF
ZINC ORTHOSILICATE Zn_2SiO_4
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1
2
3
4
— // a – AXIS
— // c – AXIS
— POLYCRYSTALLINE

FIGURE 211

SPECIFICATION TABLE 211. THERMAL LINEAR EXPANSION OF ZINC ORTHOSILICATE Zn_2SiO_4

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	314	Went, Pu-Yi, Brown, J.J., and Hummel, F.A.	1964	X	293-1308	Sample A1 $2ZnO \cdot SiO_2$	73.04 ZnO and 26.96 SiO_2; specimen prepared from c.p. grade ZnO and silicic acid mixed together, dried, and heat treated; expansion measured along a-axis.
2	314	Went, Pu-Yi, et al.	1964	X	293-1308	Sample A1 $2ZnO \cdot SiO_2$	The above specimen; expansion measured along c-axis.
3	314	Went, Pu-Yi, et al.	1964	L	293-1265	Sample A1 $2ZnO \cdot SiO_2$	73.04 ZnO and 26.96 SiO_2; specimen prepared from c.p. grade ZnO and silicic acid mixed together, dried, pressed into 1 x 1 x 10 cm bar at 500 psi, and heat treated; heating rate 125 C per hr.
4	128	Wisely, H.R.	1962	L	373-973		Bar specimen 0.25 x 0.37 x 2 in.; prepared under pressure 26,000 psi, sintered 2 hr at 1400 C in air atmosphere; phase composition verified by x-ray identification.

DATA TABLE 211. THERMAL LINEAR EXPANSION OF ZINC ORTHOSILICATE Zn_2SiO_4

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 3	
293	0.000	293	0.000*
555	0.101	473	0.018
936	0.216	773	0.100
1123	0.237	973	0.158
1308	0.345	1265	0.264
CURVE 2		CURVE 4	
293	0.000*	373	0.02
555	0.118	673	0.09
936	0.290	973	0.20
1123	0.376		
1308	0.451		

* Not shown in figure.

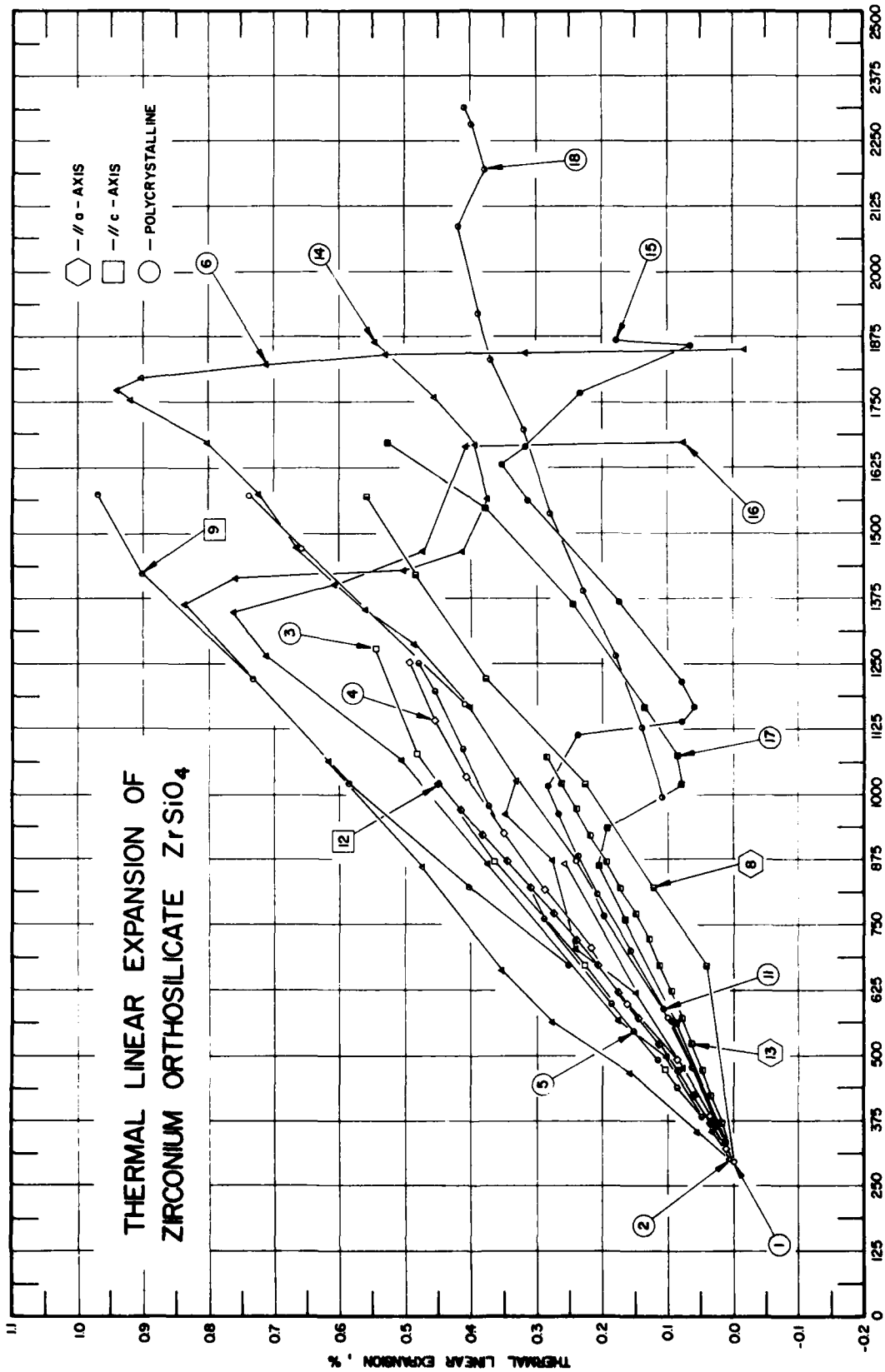

THERMAL LINEAR EXPANSION OF ZIRCONIUM ORTHOSILICATE $ZrSiO_4$
// a - AXIS
// c - AXIS
POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
125
250
375
500
625
750
875
1000
1125
1250
1375
1500
1625
1750
1875
2000
2125
2250
2375
2500

FIGURE 212

SPECIFICATION TABLE 212. THERMAL LINEAR EXPANSION OF ZIRCONIUM ORTHOSILICATE $ZrSiO_4$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	298-1573	$ZrO_2 \cdot SiO_2$	Specimen 0.5 x 0.5 x 7 in.; fine grain; ends sawed at a rake and to a point.
2	59	Bobrowsky, A.R.	1949		300, 866		No details given.
3	21	Mullineaux, J.L.	1963		295-1472	grad RZS 136	Rod specimen 0.375 in. diameter, 3 ft. long; obtained from the Norton Company; expansion before and after thermal cycling identical.
4	31	Mason, C.R., Walton, J.D., Bowen, M.D., Teague, W.T., and Murphy, C.A.	1960		321-1254	no. 1169-3-7A	Arc-sprayed tubular specimen 0.953 cm I.D., 1.27 cm O.D., 3.8 to 5 cm long; formed by spraying 20 to 50 μ particles onto brass tube, then removing brass by leaching in dilute nitric acid; density 2.62 g cm^{-3}.
5	31	Mason, C.R., et al.	1960		321-1254	no. 1169-2-4A	Similar to the above specimen; density 3.13 g cm^{-3}.
6	246	Norton, F.H.	1925	O	293-1850	Florida zircon	66.43 ZrO_2, 30.80 SiO_2, 1.78 Al_2O_3, 0.50 TiO_2, 0.37 undetermined; white specimen 1 in. square, 9 in. long; fired at 1650 C for 2 hr; ends accurately ground; heating rate 100 C per hr; reported error ± 0.01%.
7*	69	Finlay, G.R.	1952		293, 1073		Specimen density 4.34 g cm^{-3}.
8	317	Subbarao, E.C. and Gokkale, K.V.G.K.	1968	X	298-1573	Florida zircon	Filtered CuKα radiation used; expansion measured along a-axis.
9	317	Subbarao, E.C. and Gokhale, K.V.G.K.	1968	X	298-1573	Florida zircon	The above specimen; expansion measured along c-axis.
10*	317	Subbarao, E.C. and Gokhale, K.V.G.K.	1968	L	298, 1123	Florida zircon	Similar to the above specimen; cylindrical specimen, 0.375 in. diameter, 1.5 in. long; sintered at 1100 C.
11	145	Gangler, J.J.	1950	L	367-881	Zircon	Hot pressed specimen.
12	11	Austin, J.B.	1931	I	298-1073		Specimen cut from single blue zircon crystal; obtained from Chantaboon, Siam; expansion measured parallel principle axis.
13	11	Austin, J.B.	1931	I	298-1073		The above specimen; expansion measured perpendicular to principal axis.
14	234	Geller, R.F. and Yavorsky, P.J.	1945	L	352-1866		Specimen heat-treated at 1700 C.
15	234	Geller, R.F. and Yavorsky, P.J.	1945	L	1866-328		The above specimen; expansion measured with decreasing temperature.
16	234	Geller, R.F. and Yavorsky, P.J.	1945	L	352-1671		Similar to the above specimen; except heat-treated at 1500 C; expansion measured with increasing temperature; zero-point correction 0.700%.
17	234	Geller, R.F. and Yavorsky, P.J.	1945	L	1671-335		The above specimen; expansion measured with decreasing temperature.
18	318	Neel, D.S., Pears, C.D., and Oglesby, S.	1962	L	293-2316	Taylor zircon CZ-5	Specimen initial length 2.9420 in.; obtained from the Charles Taylor Scons Co.; density 4.3 g cm^{-3} at 25 C before test; expansion measured in helium atmosphere; reported error 2%.
19*	773	Worlton, T.G.	1972	X	298, 1223		High purity zircon powder specimen (325 mesh size) from Cerac Inc. (Butler, Wis.) and spectroscopic analysis showed the impurities to be (in wt%) Mg 0.001-0.01, Al 0.02-0.1, Ti 0.005-0.02, Hf 1.0; expansion measured along a-axis; 6.606 Å reported at 298 K.
20*	773	Worlton, T.G.	1972	X	298, 1223		The above specimen; except expansion measured along c-axis; 5.9946 Å reported at 298 K.

DATA TABLE 212. THERMAL LINEAR EXPANSION OF ZIRCONIUM ORTHOSILICATE $ZrSiO_4$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
298	0.00
573	0.10
873	0.24
1173	0.41
1473	0.66
1573	0.74

CURVE 2

T	$\Delta L/L_0$
300	0.003
866	0.259

CURVE 3

T	$\Delta L/L_0$
295	0.005*
474	0.104
673	0.226
873	0.364
1078	0.483
1278	0.544
1472	0.656*

CURVE 4

T	$\Delta L/L_0$
321	0.011
383	0.036
490	0.089
599	0.161
708	0.218
816	0.289
925	0.350
1035	0.408
1143	0.455
1254	0.494

CURVE 5

T	$\Delta L/L_0$
321	0.015*
383	0.048
437	0.087
490	0.115
546	0.150
599	0.185
762	0.289
925	0.354*
981	0.372

CURVE 5 (cont.)

T	$\Delta L/L_0$
1088	0.412
1198	0.455
1254	0.480

CURVE 6

T	$\Delta L/L_0$
293	0.000*
479	0.079
621	0.149
706	0.240
873	0.276
964	0.348
1027	0.331
1165	0.402
1288	0.486
1355	0.561
1474	0.665
1574	0.724
1672	0.802
1752	0.922
1774	0.942
1797	0.905
1822	0.713
1840	0.530
1845	0.317
1850	-0.019

CURVE 7*

T	$\Delta L/L_0$
293	0.00
1073	0.35

CURVE 8

T	$\Delta L/L_0$
298	0.000*
673	0.045
823	0.121
1023	0.227
1223	0.378
1423	0.484
1573	0.560

CURVE 9

T	$\Delta L/L_0$
298	0.000*
673	0.251

CURVE 9 (cont.)

T	$\Delta L/L_0$
823	0.402
1023	0.586
1223	0.736
1423	0.904
1573	0.971

CURVE 10*

T	$\Delta L/L_0$
298	0.00
1123	0.35

CURVE 11

T	$\Delta L/L_0$
367	0.025
478	0.063
589	0.106
700	0.156
811	0.207
881	0.238

CURVE 12

T	$\Delta L/L_0$
298	0.002*
323	0.012*
373	0.034
423	0.060
473	0.084
523	0.114
573	0.144
623	0.174
673	0.206
723	0.240
773	0.273
823	0.310
873	0.346
923	0.382
973	0.415
1023	0.450
1073	0.482*

CURVE 13

T	$\Delta L/L_0$
298	0.001*
323	0.007*
373	0.019
423	0.033

CURVE 13 (cont.)

T	$\Delta L/L_0$
473	0.047
523	0.062
573	0.079
623	0.093
673	0.111
723	0.129
773	0.148
823	0.171
873	0.193
923	0.219
973	0.239
1023	0.262
1073	0.285

CURVE 14

T	$\Delta L/L_0$
352	0.054
465	0.157
563	0.277
665	0.354
860	0.474
1064	0.619
1363	0.837
1418	0.760
1431	0.503
1465	0.412
1567	0.375
1669	0.394
1760	0.453
1866	0.546

CURVE 15

T	$\Delta L/L_0$
1866	-0.178
1859	-0.076
1766	0.231
1662	0.318
1632	0.351
1562	0.316
1369	0.174
1215	0.080
1168	0.060
1138	0.080
1113	0.237
1016	0.282
962	0.268

CURVE 15 (cont.)

T	$\Delta L/L_0$
765	0.199
565	0.097
328	0.013*

CURVE 16

T	$\Delta L/L_0$
352	0.031
493	0.102
567	0.175
665	0.253*
867	0.375
1066	0.507
1263	0.714
1349	0.764
1403	0.609
1469	0.473
1664	0.409
1671	0.076

CURVE 17

T	$\Delta L/L_0$
1671	0.526
1546	0.378
1365	0.244
1166	0.137
1075	0.086
1023	0.080
932	0.192
864	0.205
760	0.165
567	0.090
335	0.014

CURVE 18

T	$\Delta L/L_0$
293	0.00*
999	0.11
1127	0.14
1266	0.18
1391	0.23
1538	0.28
1699	0.32
1833	0.37
1922	0.39
2088	0.42
2199	0.38

CURVE 18 (cont.)

T	$\Delta L/L_0$
2283	0.40
2316	0.41

CURVE 19*

T	$\Delta L/L_0$
298	0.000
1223	0.303

CURVE 20*

T	$\Delta L/L_0$
298	0.000
1223	0.387

* Not shown in figure.

SPECIFICATION TABLE 213. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICATES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	18	Floyd, J.R.	1964		298-1273	$BaAl_2(SiO_4)_2$ Barium feldspar ($BaO \cdot Al_2O_3 \cdot 2SiO_2$)	Barium dialuminum orthosilicate; specimen prepared from calcined alumina, $BaCO_3$, and -325 mesh SiO_2 wet milled in 3000 g batches for 24 hr with 4500 g of 1 in. diameter alumina balls in 5.5 qt. alumina mills, dried to 200 C, formed into pressing granuels using organic binder, dry pressed, fired to 1923 K at average heating rate of 373 K per hr; soaked for 3 hr, and cooled at average rate of about 100 C per hr; data from smoothed curve.
2*	18	Floyd, J.R.	1964		298-1273	$Ca_2Al_2SiO_7$ Gehlenite ($2CaO \cdot Al_2O_3 \cdot SiO_2$)	Calcium aluminum silicate; specimen prepared from calcined alumina, $CaCO_3$, and -325 mesh SiO_2 wet milled in 3000 g batches for 24 hr with 4500 g of 1 in. diameter alumina balls in 5.5 qt. alumina mills, dried to 473 K, formed into pressing granules using organic binder, dry pressed, fired to 1650 C at average heating rate of 273 K per hr; soaked for 3 hr, and cooled at average rate of about 273 K per hr; data from smoothed curve.
3*	128	Wisely, H.R.	1962	L	373-973	$Ca_2Al_2SiO_7$ Gehlenite ($2CaO \cdot Al_2O_3 \cdot SiO_2$)	Calcium aluminum silicate; bar specimen, 0.25 x 0.75 x 1 in.; pressed under pressure 26,000 psi; sintered 2 hr at 1350 C in air atmosphere.
4*	154	Rigby, G.R. and Green, A.T.	1942	L	373-1473	$Ca_2Al_2SiO_7$ Gehlenite ($2CaO \cdot Al_2O_3 \cdot SiO_2$)	Calcium aluminum silicate; specimen prepared from china clay, hydrated alumina, lime and 2.0% calcium borate as mineralizer; heated to 1350 C; crystals as tablets; crystallographic axis orientated at right angle to length.
5*	128	Wisely, H.R.	1962	L	373-973	Co_2SiO_4	Cobalt orthosilicate; bar specimen, 0.25 x 0.375 x 2 in.; formed under pressure 26,000 psi; sintered 2 hr at 1400 C in nitrogen atmosphere.
6*	113	Curtis, C.E., Doney, L.M., and Johnson, J.R.	1954	L	493, 1573	$HfSiO_4$ ($HfO_2 \cdot SiO_2$)	Hafnium orthosilicate; bar specimen 0.5 x 3 x 3 in.; prepared from Hafnia and 325 mesh silica, blended and heated at 1550 C for 2 hr, cooled slowly in furnace; pressed into bar; heating rate 3 C per min.
7*	251	Cline, C.F. and Lewis, G.	1957	L	298, 1623	$HfSiO_4$	Hafnium orthosilicate; no details given.
8*	154	Rigby, G.R. and Green, A.T.	1942	L	373-1473	$Mg_2Al_4Si_5O_{18}$ Cordierite ($2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$)	Magnesium aluminum silicate; 51.36 SiO_2, 34.86 Al_2O_3, and 13.78 MgO; obtained by heating a mixture of steatite, china clay and alumina to 1420-1440 C, resulting mix had partly fused then pulverized, rebonded with gum, sintered at 1250 C; a dial gauge actuated by a silica thrust rod.
9*	42	Kirchner, H.P., Merz, K.M., and Smyth, H.T.	1959	L	293-1253	$MnSiO_3$	Manganese metasilicate; bar specimen 4.37 in. long, 0.44 in. square; prepared by heating manganese dioxide and flint together at 1100 C for 4 hr in an electric muffle furnace; powder mixed with 15% binder solution, pressed at 5000 psi and fired at 1200 C for 2 hr to form specimen.
10*	128	Wisely, H.R.	1962	L	373-973	Ni_2SiO_4	Nickel orthosilicate; bar specimen, 0.25 x 0.37 x 2 in.; prepared under pressure 26,000 psi, sintered 2 hr at 1400 C in air atmosphere; reported error ±1%.
11*	309	Taylor, D. and Henderson, C.M.B.	1968	X	293-1192	$KAl(SiO_3)_2$ Synthetic leucite	Potassium aluminum metasilicate; specimen prepared as gel from K_2CO_3 and Al powder dissolved in nitric acid; ludox or tetrathyl orthosilicate added; crystallized in platinum capsule for 3 to 6 days at 1373 K to 1473 K; tetragonal at 25 C and invert to cubic symmetry at 605 K; expansion measured along a-axis.
12*	309	Taylor, D. and Henderson, C.M.B.	1968	X	293-844	$KAl(SiO_3)_2$ Synthetic leucite	Potassium aluminum metasilicate; teh above specimen; expansion measured along c-axis.

* No figure given.

SPECIFICATION TABLE 213. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICATES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
13*	309	Taylor, D. and Henderson, C.M.B.	1968	X	293-1192	$RbAl(SiO_3)_2$ Rb-leucite	Rubidium aluminum metasilicate; synthetic specimen, prepared as gel from Rb_2CO_3 and Al powder; dissolved in nitric acid; ludox or tetraethyl orthosilicate added; crystallized in platinum capsule for 3 to 6 days at 1373 to 1473 K; tetragonal structure at 25 C and invert to cubic symmetry at 310 C; expansion measured along a-axis.
14*	309	Taylor, D. and Henderson, C.M.B.	1968	X	293-483	$RbAl(SiO_3)_2$ Rb-leucite	Rubidium aluminum metasilicate; the above specimen; expansion measured along c-axis of tetragonal structure.
15*	315	Hummel, F.A.	1949	X	300-1273	$NaAlSiO_4$ Carnegiete	Sodium aluminum orthosilicate; bar specimen from pottery flint, c.p. Al_2O_3 and c.p. Na_2CO_3; wet milled in acetone, heated 50 hr at 1373 K and 4 hr at 1673 K; identified by x-ray determinations; sintered 1 hr at 1673 K.
16*	315	Hummel, F.A.	1949	X	300-1273	Na_2CaSiO_4	Disodium calcium orthosilicate; bar specimen prepared from c.p. Na_2CO_3, c.p. $CaCO_3$ and pottery flint, heated together 50 hr at 1373 K; compound formation verified by x-ray analysis; sintered 1 hr at 1373 K.
17*	18	Floyd, J.K.	1964		298-1273	$SrAl_2(SiO_4)_2$ ($SrO \cdot Al_2O_3 \cdot 2SiO_2$) Strontium feldspar	Strontium dialuminum orthosilicate; specimen 0.25 in. diameter, 4 in. long; prepared from calcined alumina, $SrCO_3$, and -325 mesh SiO_2, wet mixed in 3000 g batches for 24 hr with 4500 g of 1 in. diameter alumina balls in 5.5 qt. alumina mills, dried to 200 C, formed into pressing granuels using organic binder, dry pressed, fired to 1650 C at average heating rate of about 373 K per hr, soaked for 3 hr, and cooled at average rate of about 373 K per hr.
18*	42	Kirchner, H.P., Merz, K.M., and Smyth, H.T.	1959	L	293-1203	$ThSiO_4$ ($ThO_2 \cdot SiO_2$)	Thorium metasilicate; bar specimen 4.39 in. long, 0.44 in. square; prepared by heating thorium nitrate and flint to 1100 C for 4 hr in an electric muffle furnace; powder mixed with 15% binder solution, pressed at 5000 psi and fired at 1300 C for 2 hr to form specimen; reported error ±2%.
19*	316	Keler, E.K. and Kuznetsov, A.K.	1962	L	273, 1473	Y_2SiO_5	Yttrium silicate; specimen prepared by reacting Y_2O_3 with SiO_2, fired at temperatures up to 1873 K; completion of reaction verified by x-ray analysis.

* No figure given.

DATA TABLE 213. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICATES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
298	0.001
373	0.031
473	0.067
573	0.103
673	0.149
773	0.193
873	0.241
973	0.301
1073	0.377
1173	0.457
1273	0.541

CURVE 2*

T	$\Delta L/L_0$
298	0.001
373	0.035
473	0.101
573	0.181
673	0.265
773	0.351
873	0.441
973	0.535
1073	0.635
1173	0.733
1273	0.853

CURVE 3*

T	$\Delta L/L_0$
373	0.063
673	0.300
973	0.573

CURVE 4*

T	$\Delta L/L_0$
373	0.067
473	0.151
573	0.230
673	0.312
773	0.397
873	0.485
973	0.572
1073	0.657
1173	0.747
1273	0.834
1373	0.930
1473	1.026

CURVE 5*

T	$\Delta L/L_0$
373	0.077
673	0.365
973	0.695

CURVE 6*

T	$\Delta L/L_0$
423	0.047
1573	0.461

CURVE 7*

T	$\Delta L/L_0$
293	0.000
1623	0.573

CURVE 8*

T	$\Delta L/L_0$
373	0.005
473	0.011
573	0.025
673	0.040
773	0.062
873	0.086
973	0.115
1073	0.144
1173	0.179
1273	0.214
1373	0.265
1473	0.310

CURVE 9*

T	$\Delta L/L_0$
293	0.000
393	0.070
493	0.170
533	0.225
653	0.350
763	0.435
843	0.510
953	0.595
1053	0.705
1138	0.770
1183	0.800
1253	0.835

CURVE 10*

T	$\Delta L/L_0$
373	0.076
673	0.361
973	0.670

CURVE 11*

T	$\Delta L/L_0$
293	0.000
304	-0.036
482	-0.095
595	-0.240
693	-0.298
794	-0.480
819	-0.698
841	-0.844
894	-1.695
992	-1.469
1043	-1.360
1092	-1.251
1192	-1.207

CURVE 12*

T	$\Delta L/L_0$
293	0.000
298	0.023
480	0.452
595	0.834
694	1.316
795	1.952
818	2.181
844	2.472

CURVE 13*

T	$\Delta L/L_0$
293	0.000
304	-0.029
424	-0.183
485	-0.329
595	-0.834
647	-0.724
696	-0.651
747	-0.563
795	-0.505
893	-0.490
920	-0.490
994	-0.410
1092	-0.395
1192	-0.359

CURVE 14*

T	$\Delta L/L_0$
293	0.000
301	0.037
421	0.360
483	0.750

CURVE 15*

T	$\Delta L/L_0$
300	0.01
323	0.04
374	0.09
423	0.13
475	0.21
523	0.27
573	0.35
624	0.43
674	0.51
723	0.60
773	0.69
822	0.79
873	0.88
923	1.04
972	1.25
1024	1.36
1073	1.46
1123	1.55
1174	1.64
1223	1.71
1273	1.77

CURVE 16*

T	$\Delta L/L_0$
300	0.01
323	0.06
373	0.11
423	0.20
474	0.29
524	0.37
572	0.47
623	0.57
671	0.68
723	0.79
773	0.90
824	1.01
873	1.14
923	1.31
972	1.49

CURVE 16 (cont.)*

T	$\Delta L/L_0$
1023	1.64
1075	1.79
1123	1.89
1174	1.96
1223	1.98
1273	1.94

CURVE 17*

T	$\Delta L/L_0$
298	0.000
373	0.024
473	0.056
573	0.088
673	0.128
773	0.166
873	0.208
973	0.264
1073	0.334
1173	0.408
1273	0.508

CURVE 18*

T	$\Delta L/L_0$
293	0.000
353	0.040
423	0.125
533	0.330
693	0.560
793	0.720
903	0.800
983	0.820
1085	0.840
1203	0.841

CURVE 19*

T	$\Delta L/L_0$
273	-0.01
1473	0.51

* No figure given.

SPECIFICATION TABLE 214. THERMAL LINEAR EXPANSION OF CESIUM SULFATE Cs_2SO_4

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	774	Auby, R., Bernard, M.S., and Massaux, M.	1968	X	293-913		Pure powder specimen; weak first order transformation at 320 C, stronger second order transformation at 460 C; transforms from orthorhombic to hexagonal crystal structure above ~ 660 C; expansion measured using copper Kα radiation along a-axis.
2*	774	Auby, R., et al.	1968	X	293-913		The above specimen; expansion measured along b-axis.
3*	774	Auby, R., et al.	1968	X	293-913		The above specimen; expansion measured along c-axis.

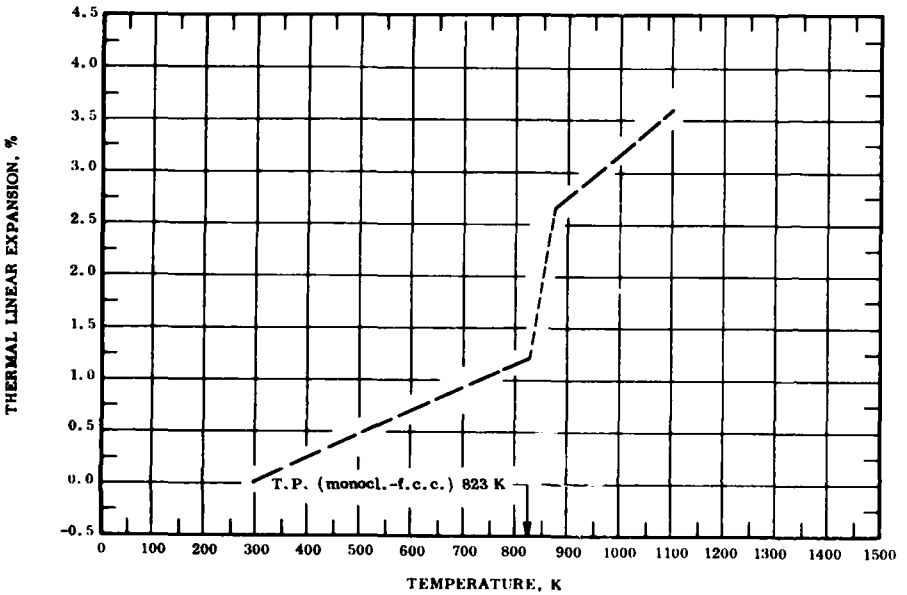
DATA TABLE 214. THERMAL LINEAR EXPANSION OF CESIUM SULFATE Cs_2SO_4

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*		CURVE 3*	
293	0.000	293	0.000	293	0.000
423	0.575	423	0.385	423	0.304
548	1.390	548	1.099	548	0.886
621	1.550	621	1.457	621	1.226
691	2.077	691	1.484	691	1.954
753	2.332	753	1.805	753	2.501
873	2.796	873	2.061	873	4.164
913	2.955	913	2.071	913	5.014

* No figure given.

FIGURE AND TABLE NO. 215R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF LITHIUM SULFATE Li_2SO_4



PROVISIONAL VALUES

(*Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}*)

T	$\Delta L/L_0$	α
293	0.000	21.6
350	0.127	21.9
400	0.237	22.1
450	0.348	22.3
500	0.455	22.5
550	0.575	22.7
600	0.687	22.8
650	0.802	23.0
700	0.917	23.1
750	1.032	23.2
800	1.150	23.2
823†	1.202	23.2
873†	2.65	39.5
900	2.75	40.5
950	2.95	42.3
1000	3.17	43.2
1050	3.40	43.5
1100	3.60	44.0

† Transition temperature from monoclinic structure to faced-centered cubic structure.

REMARKS

The provisional values are considered accurate to within ±7% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.606 + 1.978 \times 10^{-3}\, T + 3.739 \times 10^{-7}\, T^2 - 1.326 \times 10^{-10}\, T^3 \quad (293\text{-}823\ K)$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ±10%.

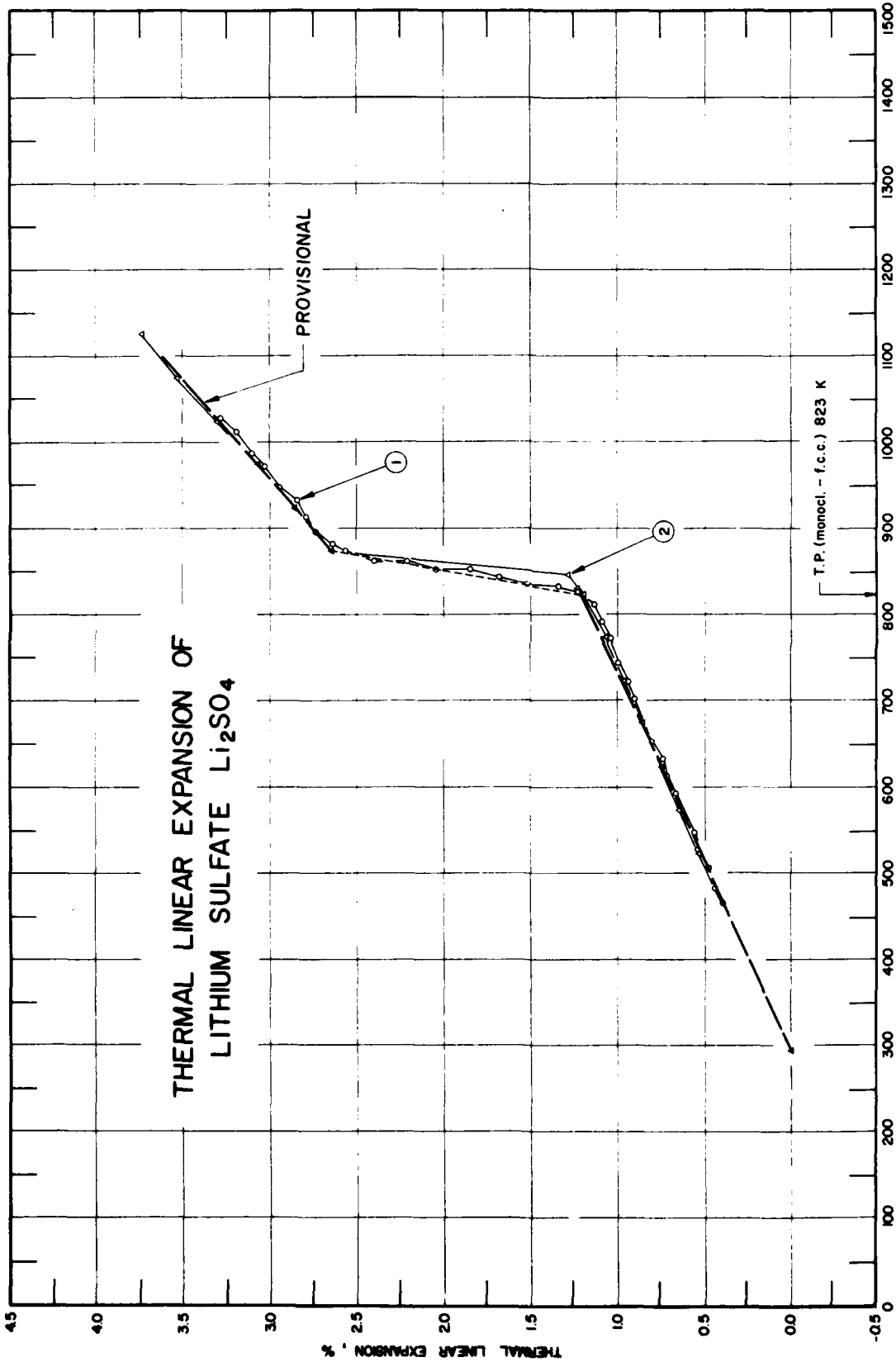

THERMAL LINEAR EXPANSION OF
LITHIUM SULFATE Li_2SO_4
PROVISIONAL
1
2
T.P. (monocl. - f.c.c.) 823 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 215

SPECIFICATION TABLE 215. THERMAL LINEAR EXPANSION OF LITHIUM SULFATE Li_2SO_4

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	775	Augustsson, B. and Ekhed, A.	1968	L	478-1028		Reagent grade lithium sulphate melted in a platinum mould to obtain a square salt column of about 45 mm length after solidification; under 550 C monoclinic structure; above 600 C cubic structure; zero-point correction 0.140%.
2	776	Jansson, B. and Sjöblom, C. A.	1970	L	293-1123		Reagent grade sample from Mallinckrodt. (New York), sodium sulfates from E Merck AG. (Germany), salts dried (50 hr) at 120°, melted and mixed the moulded to 40 mm length and 10 mm diameter specimen size; phase transition from monoclinic structure to face-centered cubic structure at 873 K.

DATA TABLE 215. THERMAL LINEAR EXPANSION OF LITHIUM SULFATE Li_2SO_4

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 2	
468	0.400	827	1.230	293	0.00
483	0.440	832	1.345	523	0.53
508	0.470	835	1.520	573	0.64
528	0.538	843	1.680	623	0.75
546	0.560	851	1.850	673	0.86
573	0.640*	853	2.040	723	0.96
593	0.660	862	2.210	773	1.07
611	0.720	864	2.400	823	1.19
631	0.740	873	2.568	831	1.23
653	0.800	883	2.640	847	1.28
678	0.850*	897	2.740	873	2.64
701	0.890	913	2.790	923	2.86
723	0.940	931	2.840	973	3.07
745	0.990	948	2.940	1023	3.31
773	1.040	971	3.035	1073	3.53
793	1.090	988	3.100	1123	3.74
813	1.138	1011	3.180		
		1028	3.280		

* Not shown in figure.

SPECIFICATION TABLE 216. THERMAL LINEAR EXPANSION OF LITHIUM HYDRAZINIUM SULFATE $Li(N_2H_5)SO_4$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	777	Devanarayanan, S. and Easwaran, K.R.K.	1966	I	111-499		Orthorhombic crystal grown by a slow evaporation of saturated aqueous solution of a mixture of Li_2CO_3 and $(NH_2)_2H_2SO_4$ in a stoichiometric molar ratio; heated up to 170 C before actual measurements; expansion along the a-axis.
2*	777	Devanarayanan, S. and Easwaran, K.R.K.	1966	I	158-390		Similar to the above specimen; expansion along the b-axis.
3*	777	Devanarayanan, S. and Easwaran, K.R.K.	1966	I	98-485		Similar to the above specimen except recrystallized four times, expansion along the c-axis.

* No figure given.

DATA TABLE 216. THERMAL LINEAR EXPANSION OF LITHIUM HYDRAZINIUM SULFATE $Li(N_2H_5)SO_4$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 2*,‡		CURVE 2 (cont.)*,‡		CURVE 3 (cont.)*,‡	
111	-0.314	158	-0.097	424	0.290	192	-0.400
119	-0.305	205	-0.081	439	0.349	200	-0.368
148	-0.261	227	-0.067	450	0.396	206	-0.344
163	-0.236	243	-0.053			216	-0.307
192	-0.184	258	-0.038	CURVE 3*,‡		242	-0.206
220	-0.132	270	-0.027			263	-0.123
233	-0.107	284	-0.011	98	-0.679	292	-0.004
247	-0.082	296	0.004	118	-0.641	318	0.108
318	0.044	331	0.055	126	-0.623	356	0.289
365	0.123	348	0.085	133	-0.602	390	0.488
401	0.173	362	0.113	141	-0.575	404	0.584
413	0.186	375	0.143	147	-0.557	413	0.642
454	0.197	386	0.171	154	-0.536	418	0.673
466	0.188	397	0.202	166	-0.492	442	0.844
478	0.163	407	0.233	180	-0.441	466	1.050
499	0.099	416	0.263	186	-0.421	485	1.247

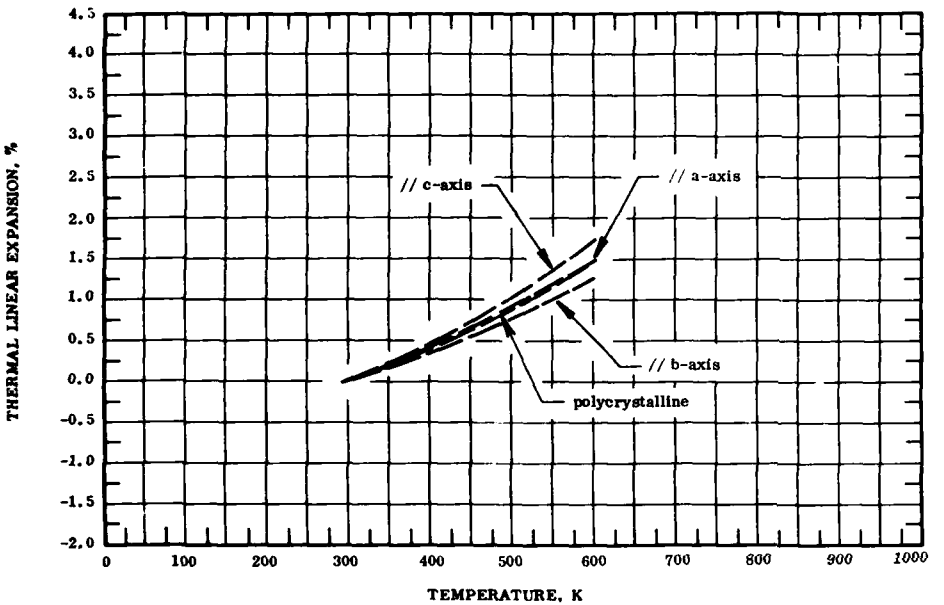
DATA TABLE 216. COEFFICIENT OF THERMAL LINEAR EXPANSION OF LITHIUM HYDRAZINIUM SULFATE $Li(N_2H_5)SO_4$

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α
CURVE 1*,‡		CURVE 2*,‡		CURVE 2 (cont.)*,‡		CURVE 3 (cont.)*,‡	
111	8.3	158	1.5	424	36.3	192	37.0
119	13.9	205	5.4	439	41.7	200	43.8
148	16.7	227	7.6	450	43.4	206	36.2
163	16.9	243	9.6			216	37.8
192	18.6	258	9.8	CURVE 3*,‡		242	39.5
220	18.9	270	10.1			263	39.9
233	18.8	284	11.9	98	17.1	292	41.8
247	17.8	296	12.9	118	20.4	318	44.8
318	17.7	331	16.5	126	24.5	356	50.3
365	15.9	348	18.7	133	35.5	390	66.7
401	11.7	362	21.2	141	32.7	404	70.0
413	10.0	375	25.2	147	28.1	413	61.0
454	-4.6	386	26.2	154	32.1	418	61.4
466	-10.0	397	30.2	166	40.2	442	80.8
478	-32.9	407	31.7	180	33.9	466	93.4
499	-27.3	416	33.1	186	32.1	485	115.4

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 217R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF POTASSIUM SULFATE K_2SO_4



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// b-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	0.000	40
350	0.245	0.197	0.248	0.229	41
400	0.460	0.375	0.478	0.438	43
450	0.693	0.569	0.735	0.666	47
500	0.937	0.785	1.020	0.914	53
550	1.184	1.024	1.355	1.194	60
600	1.497	1.298	1.748	1.514	68

REMARKS

The provisional values for the axial thermal expansion are based on the data for pure samples. The values for the polycrystalline sample are calculated from the axial values. These values are considered accurate to within ±7% and are represented approximately by the following equation:

$$\underline{//\ a\text{-axis}}: \quad \Delta L/L_0 = -1.414 + 6.006 \times 10^{-3}\, T - 6.043 \times 10^{-6}\, T^2 + 6.865 \times 10^{-9}\, T^3$$

$$\underline{//\ b\text{-axis}}: \quad \Delta L/L_0 = -1.176 + 5.341 \times 10^{-3}\, T - 6.924 \times 10^{-6}\, T^2 + 8.155 \times 10^{-9}\, T^3$$

$$\underline{//\ c\text{-axis}}: \quad \Delta L/L_0 = -1.680 + 8.474 \times 10^{-3}\, T - 1.388 \times 10^{-5}\, T^2 + 1.548 \times 10^{-8}\, T^3$$

$$\underline{\text{polycrystalline}}: \quad \Delta L/L_0 = -1.420 + 6.564 \times 10^{-3}\, T - 8.794 \times 10^{-6}\, T^2 + 1.000 \times 10^{-8}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ±10%.

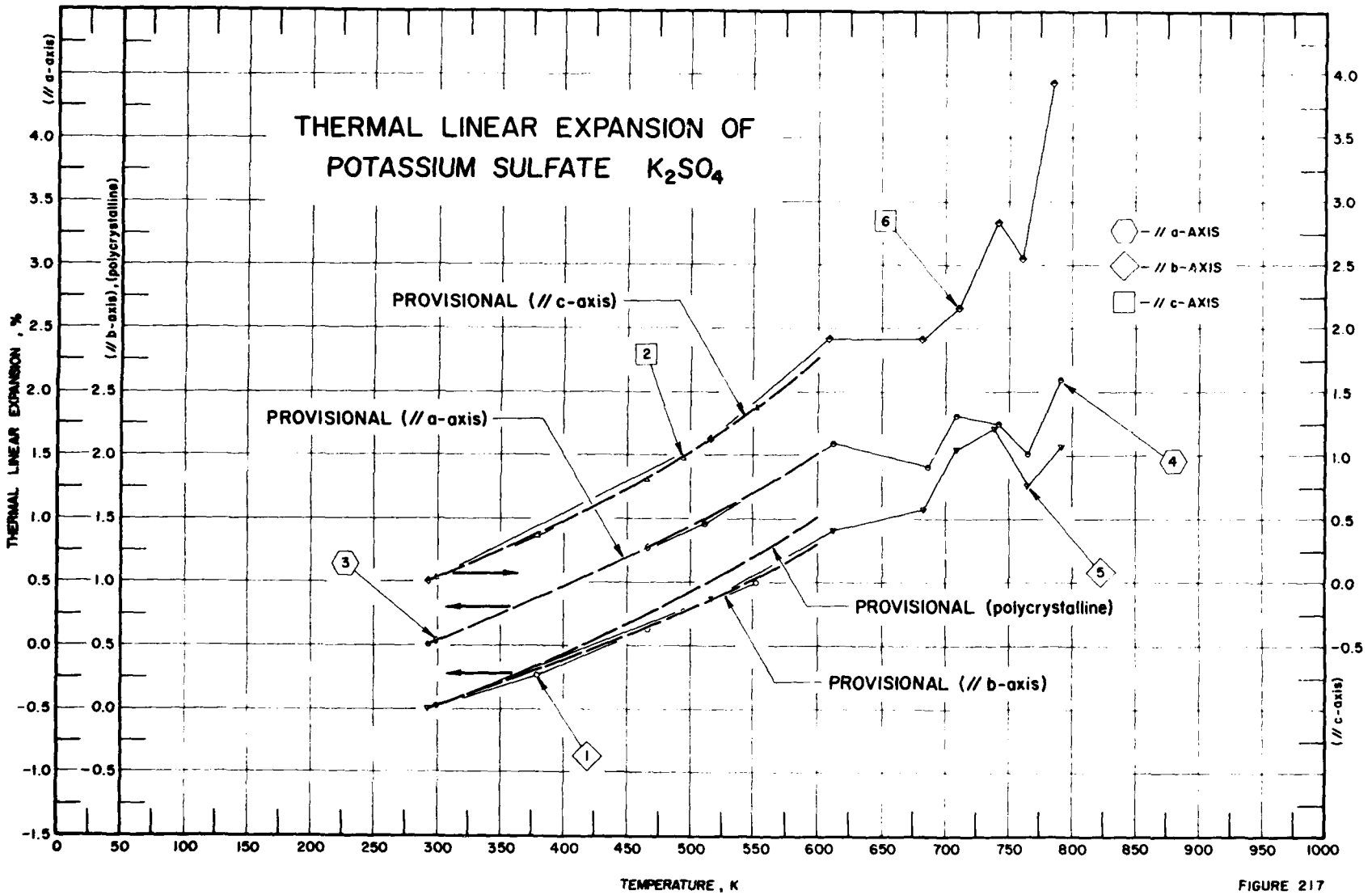

THERMAL LINEAR EXPANSION OF
POTASSIUM SULFATE K_2SO_4
PROVISIONAL (// c-axis)
PROVISIONAL (// a-axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// b-axis)
// a-AXIS
// b-AXIS
// c-AXIS
THERMAL LINEAR EXPANSION , %
(// a-axis)
(// b-axis), (polycrystalline)
(// c-axis)
TEMPERATURE , K

FIGURE 217

SPECIFICATION TABLE 217. THERMAL LINEAR EXPANSION OF POTASSIUM SULFATE K_2SO_4

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	778	Kirshna, Rao, K.V., Venkateswara, Rao, P., and Satyanarayana, M.K.	1969	X	299-551		Crystal, zero-layer weissenberg photographs recorded at different temperature; expansion measured along [010] plane, of orthorhombic structure.
2	778	Kirshna, Rao, K.V., et al.	1969	X	299-551		The above specimen; expansion measured along [001] plane.
3	778	Kirshna, Rao, K.V., et al.	1969	X	299,465		The above specimen; expansion measured along [100] plane.
4	787	Fischmeister, H.F.	1962	X	293-1165		Expansion measured along a-axis; transition of orthorhombic to hexagonal at 858 K.
5	787	Fischmeister, H.F.	1962	X	293-792		The above specimen; expansion measured along b-axis.
6	787	Fischmeister, H.F.	1962	X	293-1165		The above specimen; expansion measured along c-axis.

DATA TABLE 217. THERMAL LINEAR EXPANSION OF POTASSIUM SULFATE K_2SO_4

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %)

T	$\Delta L/L_0$
CURVE 1	
299	0.018
378	0.265
465	0.631
493	0.764
551	0.996
CURVE 2	
299	0.025
378	0.358
465	0.805
493	0.970
551	1.360
CURVE 3	
299	0.026
465	0.764

T	$\Delta L/L_0$
CURVE 4	
293	0.000 orthorh.
511	0.952
612	1.593
687	1.403
709	1.801
742	1.749
765	1.507
791	2.096
T	a(Å)
862	5.838*h.
889	5.854*
917	5.871*
944	5.880*
979	5.916*
1073	5.897*
1165	5.957*

T	$\Delta L/L_0$
CURVE 5	
293	0.000
515	0.864
612	1.400
683	1.569
709	2.046
739	2.205
765	1.758
792	2.066
CURVE 6	
293	0.000 orthorh.
516	1.136
608	1.912
681	1.912
711	2.153
741	2.835
761	2.554

T	$\Delta L/L_0$
CURVE 6 (cont.)	
785	3.931
T	c(Å)
862	8.034*h.
888	8.031*
906	8.098*
931	8.174*
978	8.206*
1070	8.386*
1165	8.441*

* Not shown in figure.

SPECIFICATION TABLE 218. THERMAL LINEAR EXPANSION OF RUBIDIUM SULFATE Rb_2SO_4

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	779	Bernard, M., Chaume, P., and Massaux, M.	1967	X	293-973		Expansion measured using Kα Cu x-rays along a-axis; 5.970 Å reported at 293 K.
2*	779	Bernard, M., et al.	1967	X	293-913		The above specimen; expansion measured along b-axis; 10.418 Å reported at 293 K.
3*	779	Bernard, M., et al.	1967	X	293-973		The above specimen; expansion measured along c-axis; 7.804 Å reported at 293 K.

DATA TABLE 218. THERMAL LINEAR EXPANSION OF RUBIDIUM SULFATE Rb_2SO_4

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*		CURVE 3*	
293	0.000	293	0.000	293	0.000
417	0.503	417	0.998	417	0.615
551	1.273	551	1.747	551	1.512
609	1.474	609	2.179	609	1.640
688	1.910	688	2.361	688	2.383
757	2.211	757	2.400	757	3.152
821	2.245	821	2.553	821	3.793
913	2.513	913	2.659	913	5.459
973	2.831			973	9.047

* No figure given.

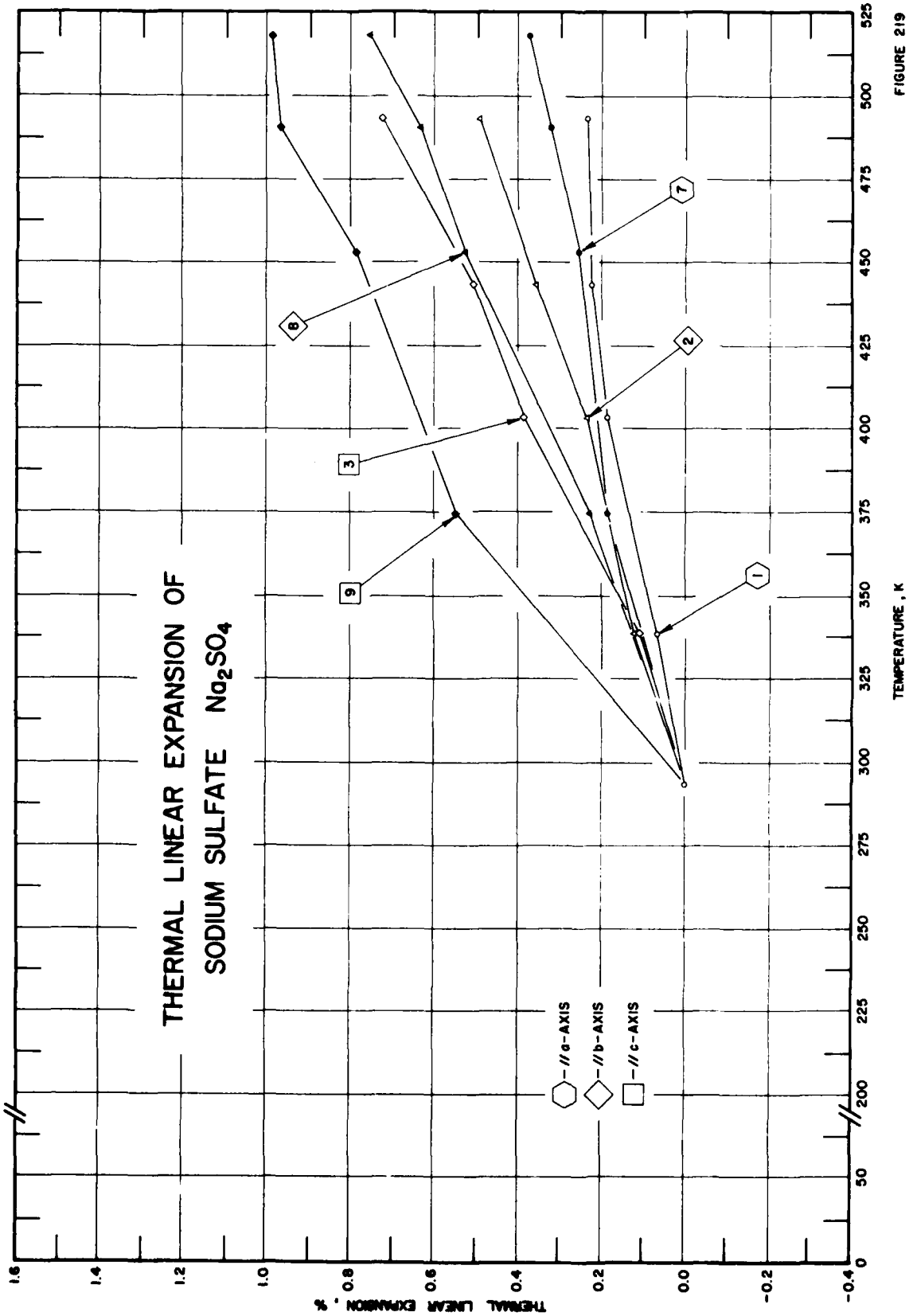

THERMAL LINEAR EXPANSION OF
SODIUM SULFATE Na_2SO_4
// a-AXIS
// b-AXIS
// c-AXIS
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
50
200
225
250
275
300
325
350
375
400
425
450
475
500
525
1
2
3
6
7
9

FIGURE 219

SPECIFICATION TABLE 219. THERMAL LINEAR EXPANSION OF SODIUM SULFATE Na_2SO_4

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	970	Tkhy, C.T.L. and Filatov, S.K.	1972	X	293-1073		X-ray diffraction patterns were recorded in air under CuKα radiation in DRON-1 x-ray diffractometer with KRV-1100 high-temperature attachment; phase transformation from orthorhombic to hexagonal at 513 K; lattice parameter measured along a-axis; 5.861 Å reported at 293 K for orthorhombic V structure.
2	970	Tkhy, C.T.L. and Filatov, S.K.	1972	X	293-493		The above specimen; lattice parameter measured along b-axis of orthorhombic V structure; 12.300 Å reported at 293 K.
3	970	Tkhy, C.T.L. and Filatov, S.K.	1972	X	293-1073		The above specimen; lattice parameter measured along c-axis; 9.821 Å reported at 293 K for orthorhombic V structure.
4*	787	Fischmeister, H.F.	1962	X	293-1069		Structure transformation from orthorhombic to hexagonal at 514 K; lattice parameter measured along a-axis; 5.592 Å reported at 293 K for orthorhombic III structure.
5*	787	Fischmeister, H.F.	1962	X	293-498		The above specimen; lattice parameter measured along b-axis of orthorhombic III structure; 8.926 Å reported at 293 K.
6*	787	Fischmeister, H.F.	1962	X	293-1063		The above specimen; lattice parameter measured along c-axis; 6.953 Å reported at 293 K for orthorhombic III structure.
7	787	Fischmeister, H.F.	1962	X	293-518		Lattice parameter measured along a-axis of orthorhombic V structure, 5.860 Å reported at 293 K.
8	787	Fischmeister, H.F.	1962	X	293-518		The above specimen; lattice parameter measured along b-axis of orthorhombic V structure, 12.302 Å reported at 293 K.
9	787	Fischmeister, H.F.	1962	X	293-518		The above specimen; lattice parameter measured along c-axis of orthorhombic V structure, 9.824 Å reported at 293 K.

* Not shown in figure.

DATA TABLE 219. THERMAL LINEAR EXPANSION OF SODIUM SULFATE Na_2SO_4

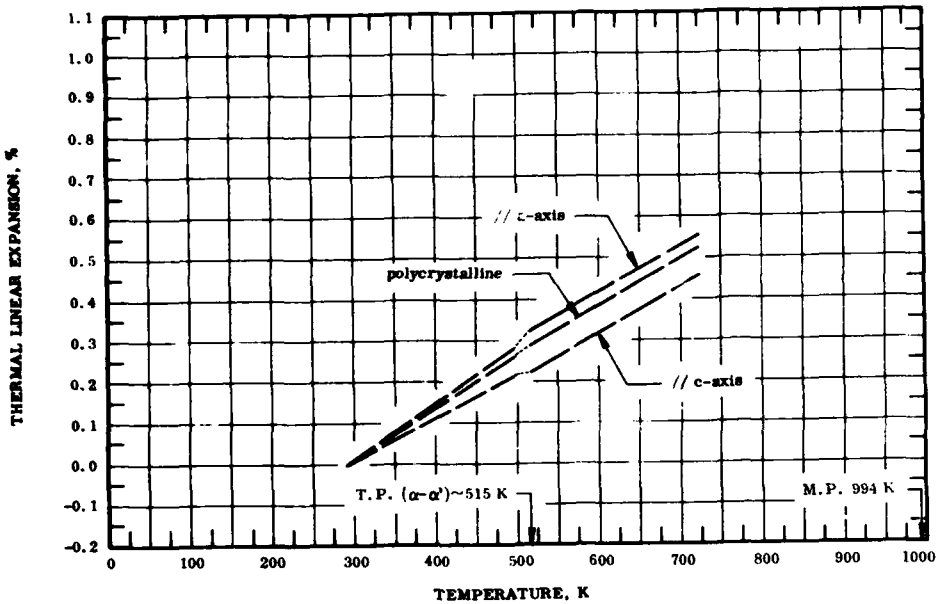
[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
338	0.068
403	0.188
443	0.222
493	0.239
T	a(Å)
523	5.446*
673	5.463*
873	5.483*
1073	5.495*
T	$\Delta L/L_0$
CURVE 2	
293	0.000*
338	0.122
403	0.236
443	0.358
493	0.496
CURVE 3	
293	0.000*
338	0.112
403	0.387
443	0.509
493	0.723
T	c(Å)
523	7.266*
673	7.385*
873	7.563*
1073	7.899*
T	$\Delta L/L_0$
CURVE 4*	
293	0.000
365	0.054
415	0.107
460	0.215
493	0.215
T	a(Å)
498	5.595
539	5.406
557	5.412
574	5.427
599	5.434
647	5.429
694	5.429
884	5.454
1069	5.487
T	$\Delta L/L_0$
CURVE 5*	
293	0.000
365	0.493
415	0.728
450	1.042
476	1.255
498	1.120
CURVE 6*	
293	0.000
365	0.288
415	0.575
464	0.834
484	1.165
497	0.805
T	c(Å)
530	7.225
534	7.217
546	7.240
562	7.255
584	7.284
641	7.327
690	7.353
886	7.508
1063	7.789
T	$\Delta L/L_0$
CURVE 7	
293	0.000*
374	0.188
453	0.256
491	0.324
518	0.375
CURVE 8	
293	0.000*
374	0.228
453	0.528
491	0.634
518	0.756
CURVE 9	
293	0.000*
374	0.550
453	0.784
491	0.967
518	0.987

* Not shown in figure.

5. NONOXIDE COMPOUNDS

FIGURE AND TABLE NO. 220R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF CADMIUM ARSENIDE Cd_3As_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	12.1
300	0.009	0.007	0.009	12.3
350	0.076	0.057	0.070	12.3
400	0.143	0.109	0.132	12.5
450	0.212	0.162	0.195	12.9
500	0.284	0.213	0.261	13.4
550†	0.357	0.254	0.322	
600	0.413	0.311	0.379	
650	0.474	0.373	0.441	
700	0.531	0.430	0.500	
725	0.555	0.457	0.521	

†Transition from α to α' near 515 K.

REMARKS

The provisional values for the axial thermal expansion are based on the data for high purity single crystal sample from the most recent measurement. The provisional values for polycrystalline sample are derived from these values. An isomorphic phase change is indicated at 515 K by a discontinuity in thermal ex, ansion curve. The provisional values are considered accurate to within ±7% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.474 + 2.055 \times 10^{-3} T - 2.089 \times 10^{-6} T^2 + 2.015 \times 10^{-9} T^3$ (293-500 K)

$\Delta L/L_0 = 0.518 - 2.843 \times 10^{-3} T + 6.650 \times 10^{-6} T^2 - 3.663 \times 10^{-9} T^3$ (550-725 K)

// c-axis: $\Delta L/L_0 = -0.172 + 5.022 \times 10^{-3} T + 2.393 \times 10^{-6} T^2 - 1.902 \times 10^{-9} T^3$ (293-500 K)

$\Delta L/L_0 = 0.249 - 2.014 \times 10^{-3} T + 5.255 \times 10^{-6} T^2 - 2.870 \times 10^{-9} T^3$ (550-725 K)

polycrystalline: $\Delta L/L_0 = -0.373 + 1.390 \times 10^{-3} T - 6.163 \times 10^{-7} T^2 + 7.439 \times 10^{-10} T^3$ (293-500 K)

$\Delta L/L_0 = 0.761 - 4.311 \times 10^{-3} T + 9.184 \times 10^{-6} T^2 - 5.091 \times 10^{-9} T^3$ (550-725 K)

The tabulated values for the coefficient of thermal expansion are derived primarily by differentiating the above equation for the polycrystalline sample. These values are considered accurate to about ±10%.

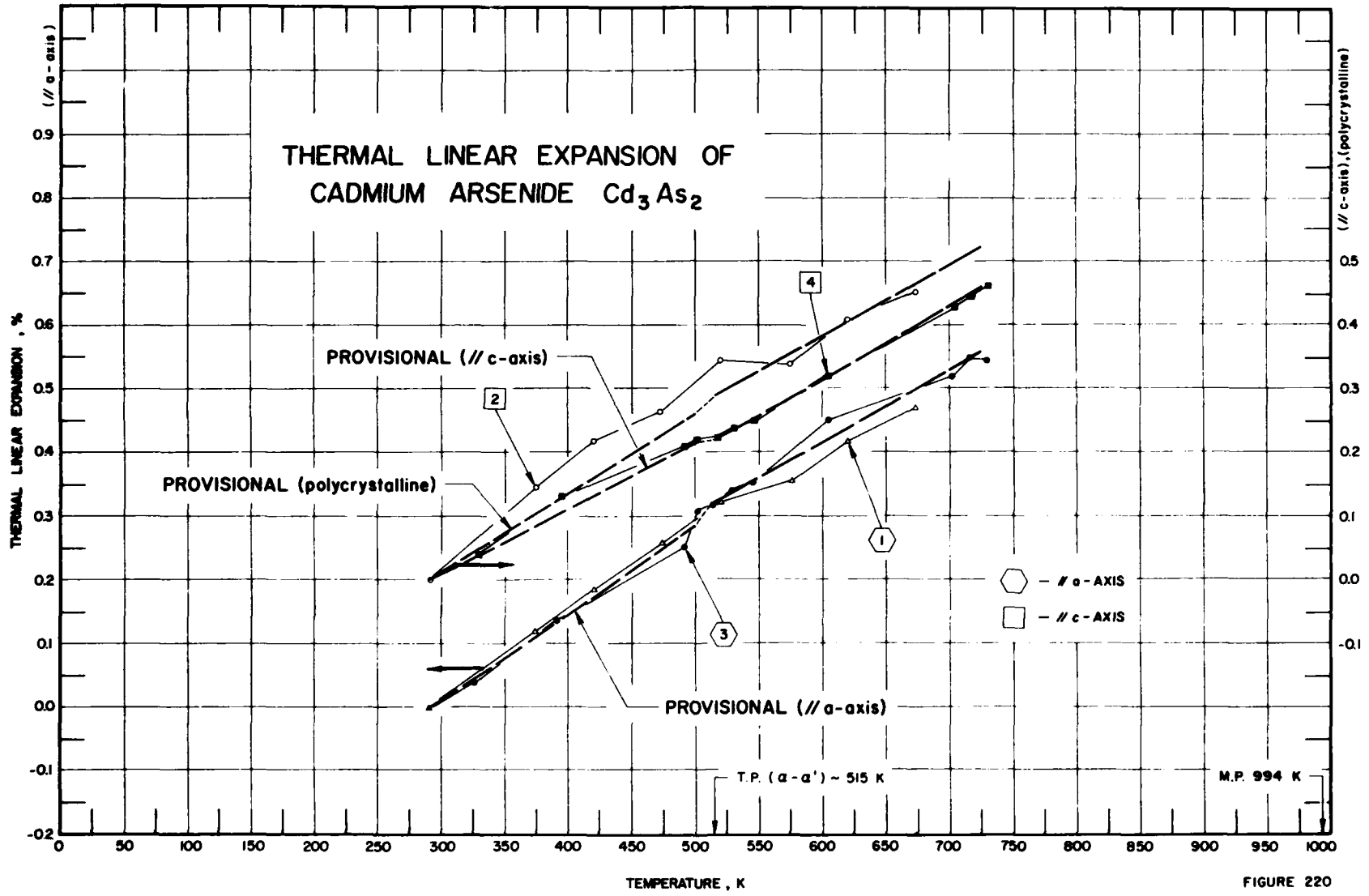

THERMAL LINEAR EXPANSION OF
CADMIUM ARSENIDE Cd_3As_2
PROVISIONAL (// c-axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// a-axis)
1
2
3
4
— // a-AXIS
— // c-AXIS
T.P. (α-α') ~ 515 K
M.P. 994 K
THERMAL LINEAR EXPANSION , %
(// a-axis)
(// c-axis), (polycrystalline)
TEMPERATURE , K
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 220

SPECIFICATION TABLE 220. THERMAL LINEAR EXPANSION OF CADMIUM ARSENIDE Cd_3As_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	601	Weglowski, S. and Lukaszewiez, K.	1968	X	291-673		Single crystal with small acicular crystal, not homogeneous; annealed at 523 K; nickel-filtered CuKα radiation applied; measured along a-axis with lattice parameter of 12.657 Å reported at 291 K; 12.657 Å at 293 K determined by graphical interpolation.
2	601	Weglowski, S. and Lukaszewiez, K.	1968	X	289-673		The above specimen except measured along c-axis; lattice parameter of 25.545 Å reported at 289 K; 25.547 Å at 293 K determined by graphical interpolation.
3	602	Pietraszko, A. and Lukaszewiez, K.	1973	X	293-791		Single crystal of high purity; grown by chemical transport method; checked by photographic methods on Weissenberg goniometer; microstructure changed several times: α phase from 293 K to 493 K, α' phase from 503 K to 729 K, α'' phase from 749 K to 791 K, and β phase from 800 K and above; lattice constants along a-axis measured and smoothed by least squares method; 12.6461 Å reported at 296 K, 12.6456 Å at 293 K determined by graphical extrapolation.
4	602	Pietraszko, A. and Lukaszewiez, K.	1973	X	293-791		The above specimen; measured along the c-axis; 25.4378 Å reported at 296 K; 25.4367 Å at 293 K determined by graphical extrapolation.

DATA TABLE 220. THERMAL LINEAR EXPANSION OF CADMIUM ARSENIDE Cd_3As_2

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %)

T	$\Delta L/L_0$
CURVE 1	
291	0.000
372	0.118
420	0.182
473	0.253
521	0.324
573	0.355
621	0.419
673	0.450
CURVE 2	
289	-0.008*
369	0.145
419	0.219
473	0.262
520	0.348
572	0.340

T	$\Delta L/L_0$
CURVE 2 (cont.)	
623	0.407
673	0.470
CURVE 3	
293	0.000
296	0.003
326	0.041
398	0.142
493	0.245
503	0.309
517	0.321
531	0.345
547	0.358
605	0.441
703	0.526
718	0.539
729	0.555

T	a(Å)
CURVE 3 (cont.)	
749	9.036
762	9.037
776	9.039
791	9.041

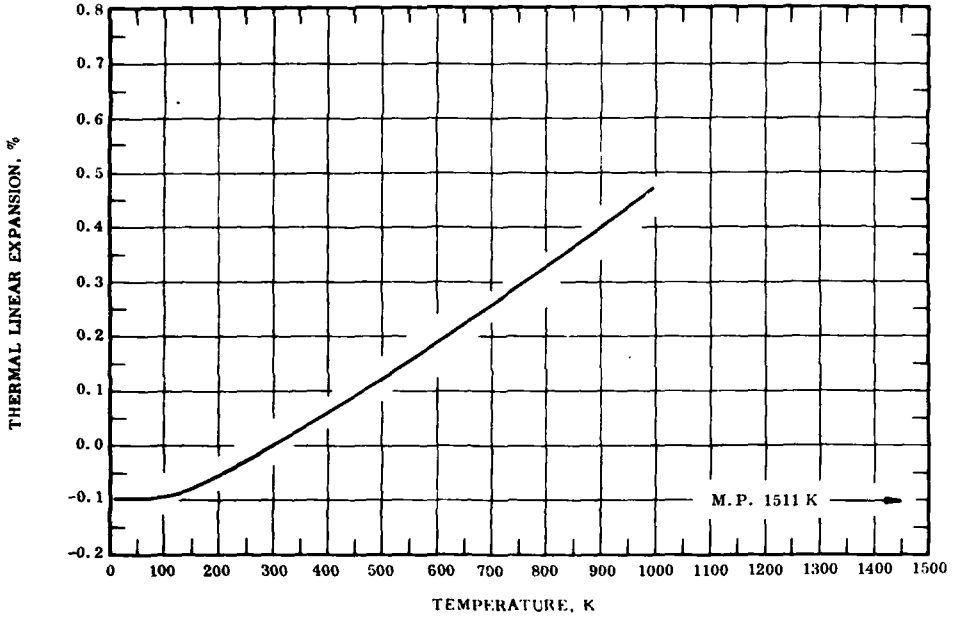
T	$\Delta L/L_0$
CURVE 4	
293	0.000*
296	0.004
326	0.045
398	0.130
493	0.212
503	0.204
517	0.223
531	0.238
547	0.254

T	$\Delta L/L_0$
CURVE 4 (cont.)	
605	0.322
703	0.425
718	0.444
729	0.462

T	c(Å)
749	12.6606
762	12.6641
776	12.6667
791	12.6669

* Not shown in figure.

FIGURE AND TABLE NO. 221R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF GALLIUM ARSENIDE GaAs



RECOMMENDED VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

T	$\Delta L/L_0$	α
5	-0.090	0.01
25	-0.090	-0.15
50	-0.090	-0.06
75	-0.090	0.9
100	-0.086	1.9
150	-0.071	3.8
200	-0.051	4.8
250	-0.024	5.4
293	0.000	5.7
300	0.004	5.7
400	0.063	6.2
500	0.126	6.5
600	0.192	6.7
700	0.261	6.9
800	0.331	7.1
900	0.403	7.2
1000	0.475	7.3

REMARKS

The recommended values are based on the data for high-purity samples and are considered accurate to within ±3% at temperatures below 600 K and ±5% above 600 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.147 + 4.239 \times 10^{-4}\, T + 2.916 \times 10^{-7}\, T^2 - 9.360 \times 10^{-11}\, T^3 \qquad (200\text{-}1000\ K)$$

The tabulated values for the coefficient of thermal expansion are primarily based on the selected experimental data. These values are considered accurate to about ±7%.

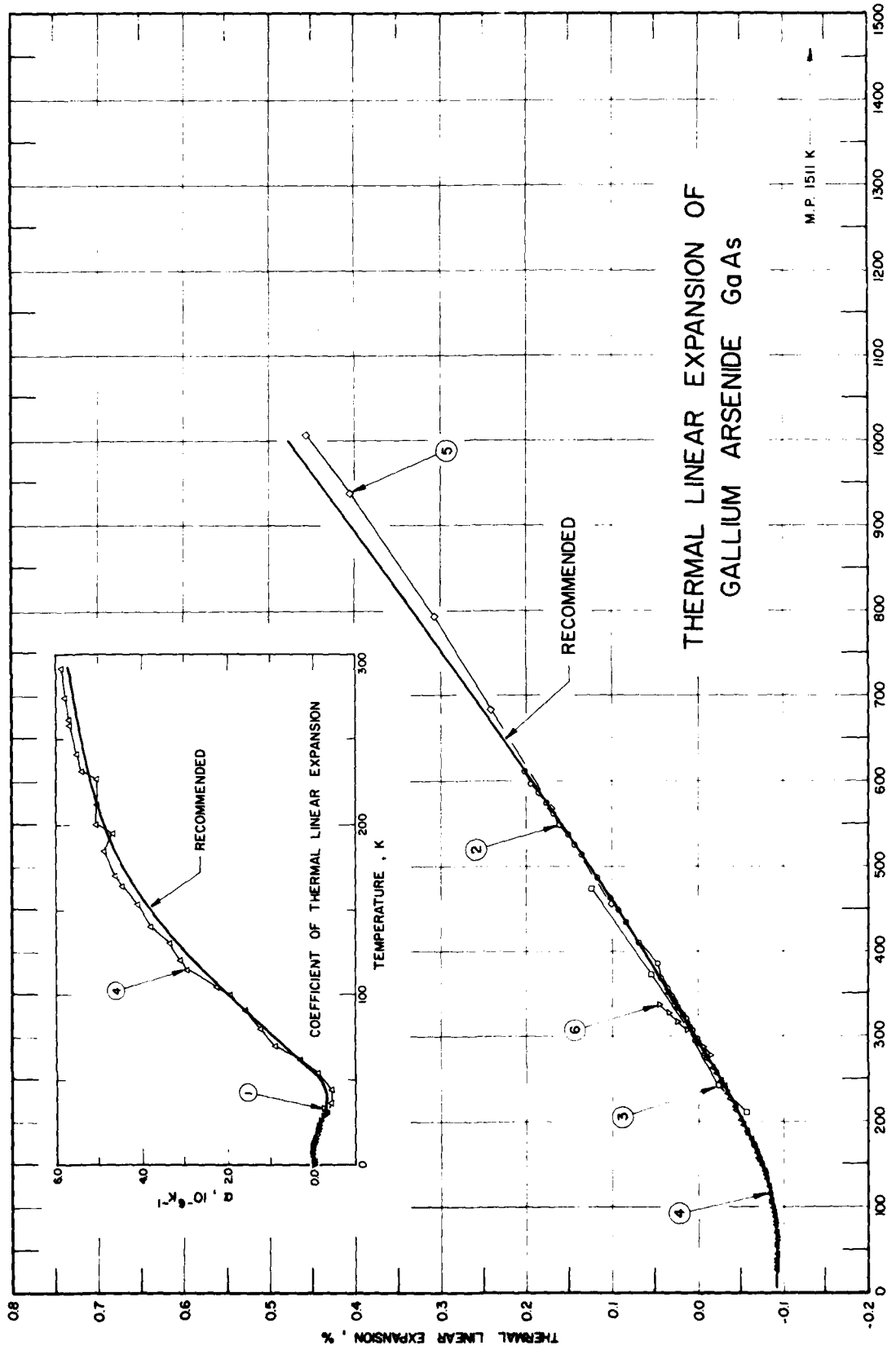

THERMAL LINEAR EXPANSION OF
GALLIUM ARSENIDE GaAs
M.P. 1511 K
RECOMMENDED
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
α , 10⁻⁶K⁻¹
TEMPERATURE , K

FIGURE 221

SPECIFICATION TABLE 221. THERMAL LINEAR EXPANSION OF GALLIUM ARSENIDE GaAs

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	461, 460	Sparks, P.W. and Swenson, C.A.	1966	V	0–40		Specimen 0.6 cm diameter, 8.26 cm long; obtained from Texas Instruments, Inc.; samples ends polished normal to its axis; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$; smooth averaged values from two runs.
2	462	Feder, R. and Light, T.	1968	X	307–609		<110> oriented, Cr-doped single crystal; faces cut and polished to parallel within 6 wavelengths; 2.5535 cm long at 298.2 K; zero-point correction of 0.0027% determined by graphical extrapolation.
3	459	Pierron, E.D., Parker, D.L., and McNeely, J.B.	1966	X	211–473		Specimen synthesized from Alcoa 99.9999 Ga and Cominco 99.9999 As; sample ground to 325 mesh and annealed at 673 K for 12 hr; expansion measured with $CuK\alpha_1$ and $CuK\alpha_2$ x-radiation; lattice parameter reported at 211.2 K is 5.6498 Å; 5.6530 Å at 293.2 K determined by graphical interpolation; reported error < 2%.
4	463	Novikova, S.I.	1961	L	28–348		Specimen smelted from spectroscopically pure elements; combination of several crystals of irregular shape; data determined in five series of measurements.
5	464	Shaw, H. and Liu, Y.H.	1965	X	296–1008		Specimen prepared from component metals of spectroscopical purity in stoichiometric proportions; further purification made by repeated zone-refining; powder taken from alloy ingot annealed at 773 K for 48 hr; lattice parameter reported at 296.2 K is 5.6411 Å; 5.6410 Å at 293.2 K determined by graphical extrapolation.
6	465	Straumanis, M.E. and Kim, C.D.	1965	X	278–338		99.94 pure specimen, approximately 0.06 Si stoichiometric material from Siemens Co.; lattice parameter reported at 278.8 K is 3.65254 Å; 3.65305 Å at 293.2 K determined by graphical interpolation.

* Not shown in figure.

DATA TABLE 221. THERMAL LINEAR EXPANSION OF GALLIUM ARSENIDE GaAs

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*,†	
0	0.0000×10^{-3}
2	0.0000
4	0.0001
6	0.0003
8	0.0009
10	0.0018
12	0.0022
14	0.0011
16	0.0025
18	0.0101
20	0.0225
22	0.0400
24	0.0625
26	0.0894
28	0.1200
30	0.1539
32	0.1893
34	0.2231
36	0.2543
38	0.2821
40	0.3053
CURVE 2	
307	0.008
330	0.021
360	0.039
389	0.057
407	0.068
435	0.085
455	0.098
484	0.117
507	0.132
535	0.151
559	0.167
579	0.180
609	0.201
CURVE 3	
211	-0.0566
243	-0.0336
297	0.0035
373	0.0548
473	0.1238
CURVE 4‡	
28	-0.093
29	-0.093
35	-0.093
37	-0.093
44	-0.093
53	-0.094
54	-0.094
62	-0.094
68	-0.093
70	-0.093
80	-0.092
82	-0.092
89	-0.091
91	-0.090
100	-0.089
105	-0.088
108	-0.087
115	-0.085
122	-0.083
122	-0.083*
131	-0.080
138	-0.078
140	-0.077
147	-0.074
154	-0.072
156	-0.071
164	-0.067
170	-0.065
171	-0.064
179	-0.060
185	-0.058
187	-0.057
196	-0.052
201	-0.050
213	-0.044
216	-0.043
227	-0.037
232	-0.034
242	-0.029
247	-0.026
258	-0.020
262	-0.018
262	-0.018*
274	-0.011
277	-0.009
CURVE 4 (cont.)‡	
277	-0.009*
292	-0.001
307	0.008
323	0.018
337	0.026
348	0.033
CURVE 5	
296	0.0017*
457	0.1010
568	0.1719
683	0.2410
793	0.3084
939	0.4059
1008	0.4573
CURVE 6	
278	-0.01396
288	-0.00629
298	0.00602*
308	0.01313
318	0.02326
328	0.03284
338	0.04571

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 221. COEFFICIENT OF THERMAL LINEAR EXPANSION OF GALLIUM ARSENIDE GaAs

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1*, †	
0	0.000000
2	0.000069
4	0.00055
6	0.00187
8	0.0044
10	0.0045
12	-0.0010
14	-0.0095
16	-0.027
18	-0.049
20	-0.075
22	-0.100
24	-0.125
26	-0.144
28	-0.162
30	-0.177
32	-0.177
34	-0.161
36	-0.151
38	-0.127
40	-0.105
CURVE 2	
307	5.61
330	5.81
360	6.02
389	6.16
407	6.22
435	6.33
455	6.47
484	6.58
507	6.60
535	6.72
559	6.70
579	6.72
609	6.82
CURVE 4‡	
28	-0.23*
29	-0.36*
35	-0.30*
37	-0.43
44	-0.43
53	-0.02*
54	-0.11
62	0.28
68	0.74*
70	0.84
80	1.20
82	1.33*
89	1.67*
91	1.59
100	1.97
105	2.22
108	2.51*
115	2.93
122	2.93*
122	3.07
131	3.31
138	3.53*
140	3.79
147	3.87*
154	4.08
156	4.36*
164	4.41
170	4.60
171	4.47*
179	4.61*
185	4.82
187	4.75*
196	4.62
201	5.01
213	5.01
216	5.06*
227	5.01
232	5.39
242	5.46
247	5.51*
258	5.66
262	5.66
262	5.56*
274	5.71
277	5.68*
277	5.73*
293	5.84
307	5.86
323	6.14
337	6.11
348	6.00

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 222. THERMAL LINEAR EXPANSION OF MISCELLANEOUS ARSENIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	603	Borshchevskii, A.S., Vaipolin, A.A., and Korshak, N.M.	1967	L	293-853	$CdSnAs_2$	Cadmium tin arsenide; monocrystalline; the coefficient of thermal expansion measured along [001] direction.
2*	603	Borshchevskii, A.S., et al.	1967	L	293-853	$CdSnAs_2$	Cadmium tin arsenide; the above specimen; measured along [110] direction.
3*	603	Borshchevskii, A.S., et al.	1967	L	293-853	$CdSnAs_2$	Cadmium tin arsenide; similar to the above specimen; polycrystalline; measured along c-axis.
4*	604	Tsuchida, T., Kawai, M., and Nakamura, Y.	1970	S	4-192	CeAs	Cerium arsenide; 99.9 purity of Ce, 99.999 purity of As; sample prepared by direct reaction of stoichiometric quantities of elements; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
5*	460	Sparks, P.W. and Swenson, C.A.	1967	V	2-42	InAs	Indium arsenide; specimen from Texas Instruments, Inc.; tested as received; smoothed data; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
6*	461	Sparks, P.W.	1966	V	0-36	InAs	Indium arsenide; specimen from Texas Instruments, Inc.; diameter 0.6 cm, length 10.01 cm at 4 K; sample ends polished normal to its axis; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
7*	605	Grazhdankina, N.P. and Burkhanov, A.M.	1966	L	292-589	MnAs	Monomanganese arsenide; specimen 4 mm in diameter and 50 mm long; photorecord data.
8*	601	Weglowski, S. and Lukaszewiez, K.	1968	X	294-769	Zn_3As_2	Zinc arsenide; single crystal; nickel-filtered CuKα radiation applied; measured along a-axis; lattice parameter 11.774 Å at 293 K used for data conversion.
9*	601	Weglowski, S. and Lukaszewiez, K.	1968	X	293-767	Zn_3As_2	Zinc arsenide; the above specimen except measured along c-axis; lattice parameter reported at 293 K is 23.646 Å.

* No figure given.

DATA TABLE 222. THERMAL LINEAR EXPANSION OF MISCELLANEOUS ARSENIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
293	0.00
693	0.12
723	0.13
853	0.19

CURVE 2*

T	$\Delta L/L_0$
293	0.00
693	0.24
723	0.26
853	0.30

CURVE 3*

T	$\Delta L/L_0$
293	0.00
693	0.22
723	0.24
853	0.27

CURVE 4*, §

T	$\Delta L/L_0$
4	0.000
5	0.014
5	0.025
6	0.032
6	0.040
6	0.048
7	0.055
8	0.058
11	0.045
14	0.055
16	0.083
19	0.117
20	0.139
22	0.180
24	0.217
29	0.283
37	0.313
42	0.324
49	0.332
57	0.339
63	0.342
65	0.344
79	0.351
94	0.361

CURVE 4 (cont.)*, §

T	$\Delta L/L_0$
115	0.377
122	0.383
151	0.410
174	0.422
192	0.430

CURVE 5*, §

T	$\Delta L/L_0$
2	-0.036×10^{-6}
4	0.000
6	-0.225
8	-2.08
10	-9.48
12	-0.277×10^{-4}
14	-0.622
16	-0.846
18	-0.130×10^{-3}
20	-0.230
22	-0.351
24	-0.489
26	-0.641
28	-0.803
30	-0.972
32	-1.14
34	-1.32
36	-1.50
38	-1.67
40	-1.84
42	-2.00

CURVE 6*, §

T	$\Delta L/L_0$
0	0.00×10^{-7}
2	0.22
4	0.00×10^{-5}
6	-0.05
8	-0.64
10	-3.48
12	-0.100×10^{-3}
14	-0.227
16	-0.396
18	-0.632
20	-0.939
22	-1.233
24	-1.660

CURVE 6 (cont.)*, §

T	$\Delta L/L_0$
26	-2.145×10^{-3}
28	-2.688
30	-3.302
32	-3.948
34	-4.59
36	-4.832

CURVE 7*

T	$\Delta L/L_0$
293	0.00
300	0.31
305	0.56
310	0.71
318	0.54
338	0.64
363	2.82
397	4.39
409	5.05
420	5.41
442	5.63
475	5.94
510	6.25
547	6.54
589	6.86

CURVE 8*

T	$\Delta L/L_0$
294	0.000
370	0.187
390	0.221
422	0.357
457	0.391
494	0.442
554	0.509
626	0.543
689	0.595
769	0.671

CURVE 9*

T	$\Delta L/L_0$
293	0.000
371	0.101
389	0.118
422	0.152
455	0.195

CURVE 9 (cont.)*

T	$\Delta L/L_0$
493	0.241
548	0.317
618	0.368
686	0.427
767	0.512

* No figure given.
§ This curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.

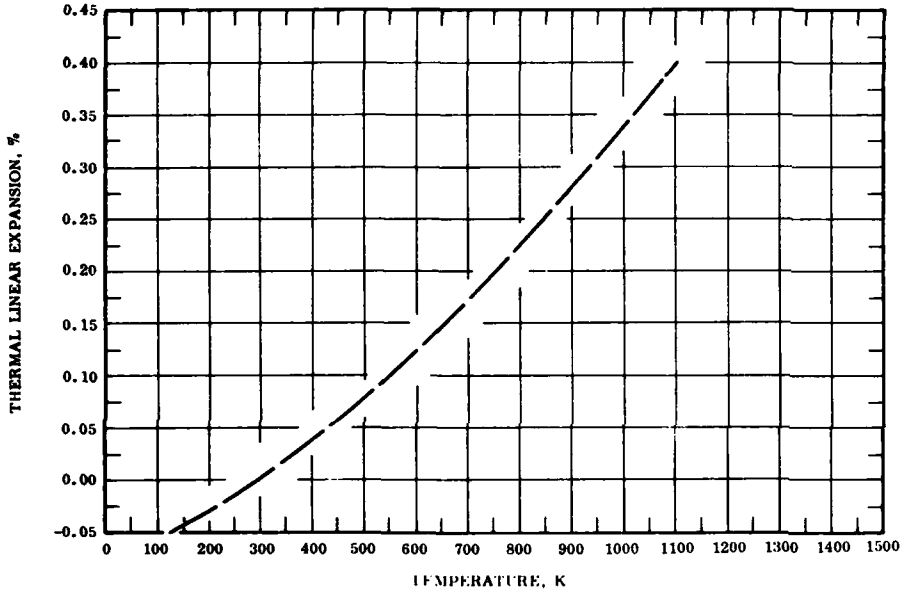
DATA TABLE 222. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS ARSENIDES

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 5*	
2	0.00011
4	0.00025
6	-0.0025
8	-0.016
10	-0.058
12	-0.125
14	-0.220
16	-0.0033
18	-0.45
20	-0.555
22	-0.65
24	-0.73
26	-0.79
28	-0.83
30	-0.86
32	-0.87
34	-0.88
36	-0.88
38	-0.86
40	-0.82
42	-0.78
CURVE 6*	
0	0.00000
2	0.00011
4	0.0000
6	-0.0025
8	-0.016
10	-0.058
12	-0.125
14	-0.227
16	-0.330
18	-0.452
20	-0.587
22	-0.685
24	-0.830
26	-0.975
28	-1.12
30	-1.27
32	-1.41
34	-1.53
36	-1.51

* No figure given.

FIGURE AND TABLE NO. 223R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ERBIUM DODECABORIDE ErB_{12}



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
100	-0.056	2.4
150	-0.043	2.7
200	-0.029	2.9
250	-0.014	3.2
293	0.000	3.4
300	0.002	3.4
350	0.020	3.6
400	0.039	3.9
450	0.059	4.1
500	0.080	4.3
600	0.125	4.7
700	0.173	5.0
800	0.225	5.4
900	0.280	5.7
1000	0.339	5.9
1100	0.399	6.2

REMARKS

The provisional values are based on the data for the high purity sample from recent measurement which follows the general trend for other dodecaborides. These values are considered accurate to within ±7% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.077 + 1.860 \times 10^{-4}\, T + 2.822 \times 10^{-7}\, T^2 - 5.232 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion for polycrystalline samples are based primarily on the selected experimental data and are considered accurate to within ±10%.

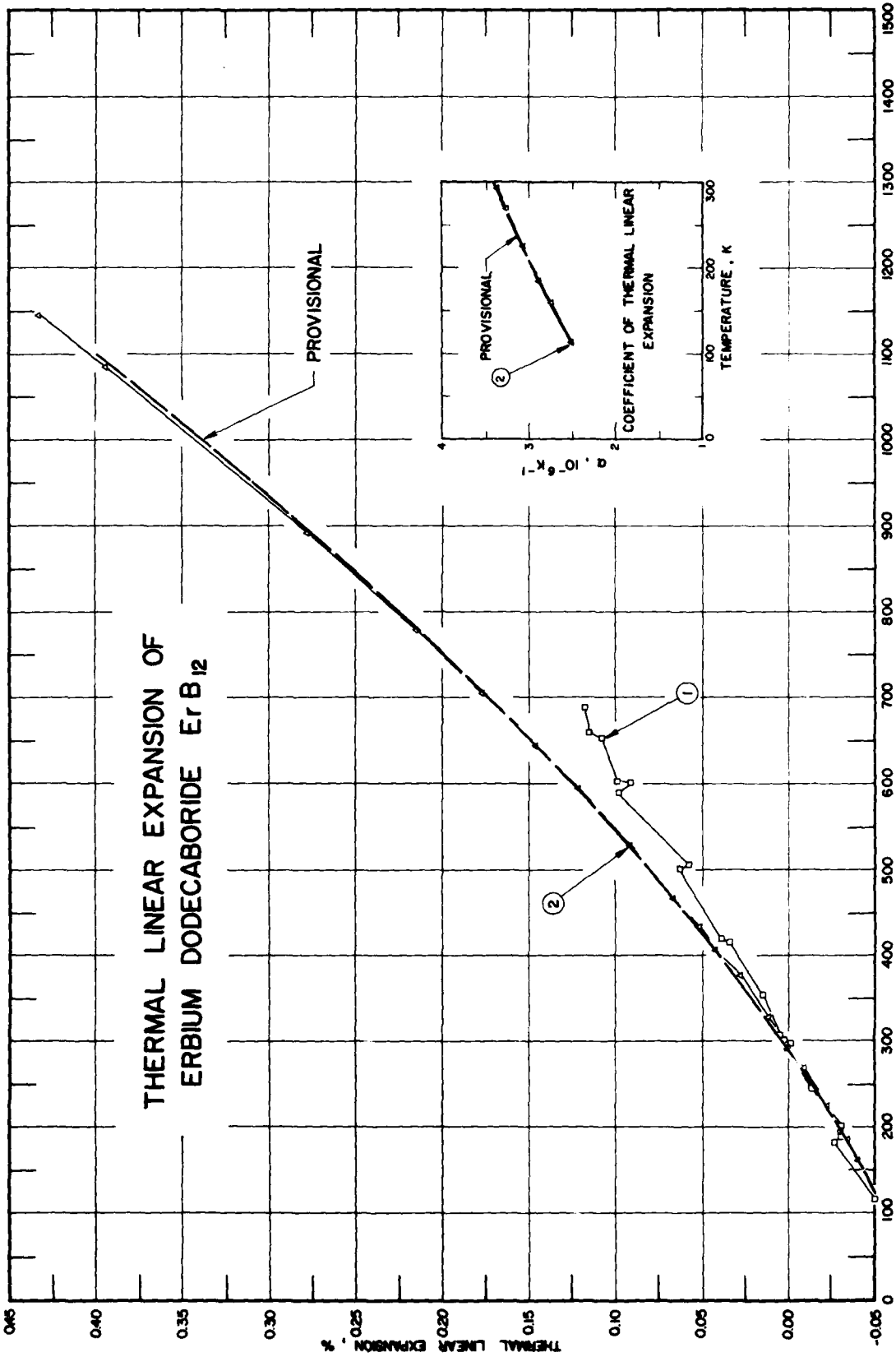

THERMAL LINEAR EXPANSION OF
ERBIUM DODECABORIDE ErB_{12}
PROVISIONAL
(1)
(2)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
$\alpha \cdot 10^{-6} K^{-1}$
PROVISIONAL
(2)
TEMPERATURE , K

FIGURE 223

SPECIFICATION TABLE 223. THERMAL LINEAR EXPANSION OF ERBIUM DODECABORIDE ErB_{12}

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	611	LaPlaca, S., Binder, I., and Post, B.	1961	X	113-688		Specimen face-centered-cubic structure; specimen prepared from sesquioxides stated as 99.9% pure, heated by induction with amorphous boron at 1673-1773 K in a protective helium atmosphere; reaction time varied from 0.5 to 1 hr; enough boron was combined with the sequioxide; lattice parameter reported as 7.48539 Å at 293 K.
2	610	Paderno, Yu.B., Odinstov, V.V., Timofeeva, I.I., and Klochkov, L.A.	1970	X/L	112-1147		Cylindrical specimens; dimensions 7 mm diameter x 10-12 mm long; made by vacuum reduction, then sintered in argon atmosphere at 2073-2173 K for 2 hr at 7465 kg/cm², x-ray method used from 13-300 K and dilatometer used from 300-1300 K.

DATA TABLE 223. THERMAL LINEAR EXPANSION OF ERBIUM DODECABORIDE ErB_{12}

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 1 (cont.)		CURVE 2‡		CURVE 2 (cont.)‡		CURVE 2 (cont.)‡	
113	-0.052	300	0.004	590	0.098	112	-0.054*	407	0.042	891	0.278
181	-0.026	308	0.006	602	0.092	159	-0.041	432	0.051	977	0.328
184	-0.033	351	0.015	612	0.099	185	-0.034*	467	0.066	1082	0.393
195	-0.035	354	0.016*	656	0.108	226	-0.022	529	0.092	1147	0.434
200	-0.034	417	0.033	660	0.115	269	-0.008	594	0.122		
245	-0.013	420	0.038	688	0.117	293	0.000*	645	0.146		
293	0.000	500	0.061			328	0.012	707	0.177		
299	-0.004	507	0.056			373	0.028	779	0.215		

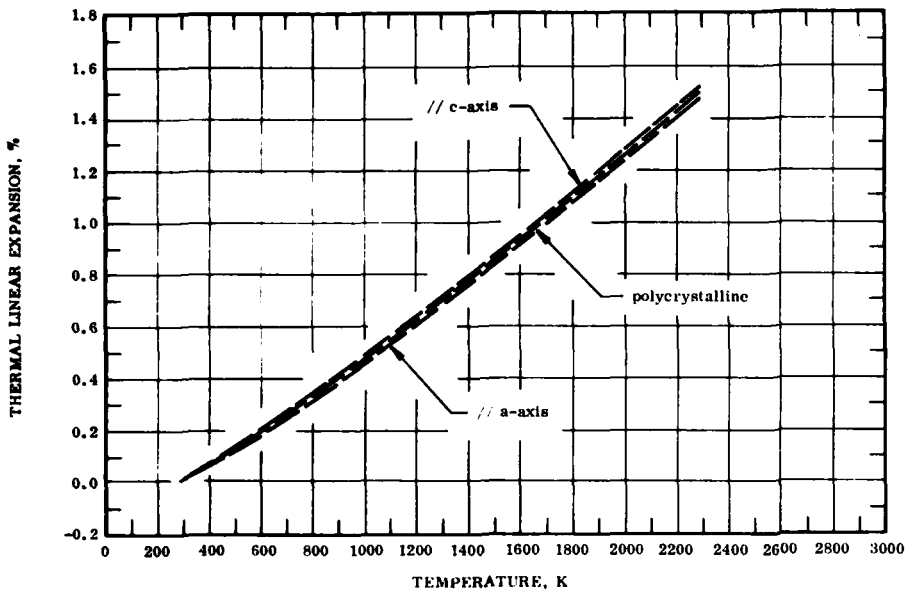
DATA TABLE 223. COEFFICIENT OF THERMAL LINEAR EXPANSION OF ERBIUM DODECABORIDE ErB_{12}

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α	T	α
CURVE 2‡		CURVE 2 (cont.)‡		CURVE 2 (cont.)‡		CURVE 2 (cont.)‡		CURVE 2 (cont.)‡	
112	2.53	269	3.27	407	3.90*	594	4.69*	891	5.77*
159	2.75	293	3.36	432	4.03*	645	4.86*	977	6.00*
185	2.89	328	3.54*	467	4.17*	707	5.11*	1082	6.25*
226	3.06	373	3.76*	529	4.43*	779	5.39*	1147	6.38*

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 224R PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF HAFNIUM DIBORIDE HfB_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	5.8
400	0.063	0.065	0.064	6.1
500	0.125	0.129	0.127	6.4
600	0.190	0.195	0.192	6.6
700	0.257	0.264	0.259	6.9
800	0.326	0.334	0.329	7.1
900	0.397	0.407	0.400	7.3
1000	0.471	0.481	0.474	7.4
1200	0.622	0.634	0.626	7.8
1400	0.780	0.792	0.784	8.0
1600	0.942	0.954	0.946	8.2
1800	1.107	1.119	1.111	8.3
2000	1.273	1.286	1.277	8.4
2200	1.441	1.453	1.445	8.4
2300	1.524	1.536	1.528	8.5

REMARKS

The provisional values for the axial thermal expansion are based on the data for powdered samples from the most recent measurement which follows the general trend for other diborides. The provisional values for polycrystalline sample are derived from these values. These values are considered accurate to within ±7% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.155 + 4.828 \times 10^{-4}\ T + 1.708 \times 10^{-7}\ T^2 - 2.747 \times 10^{-11}\ T^3$

// c-axis: $\Delta L/L_0 = -0.163 + 5.124 \times 10^{-4}\ T + 1.568 \times 10^{-7}\ T^2 - 2.540 \times 10^{-11}\ T^3$

polycrystalline: $\Delta L/L_0 = -0.158 + 4.934 \times 10^{-4}\ T + 1.655 \times 10^{-7}\ T^2 - 2.663 \times 10^{-11}\ T^3$

The tabulated values for the coefficient of thermal expansion are derived primarily by differentiating the above equation for the polycrystalline sample. These values are considered accurate to about ±10%.

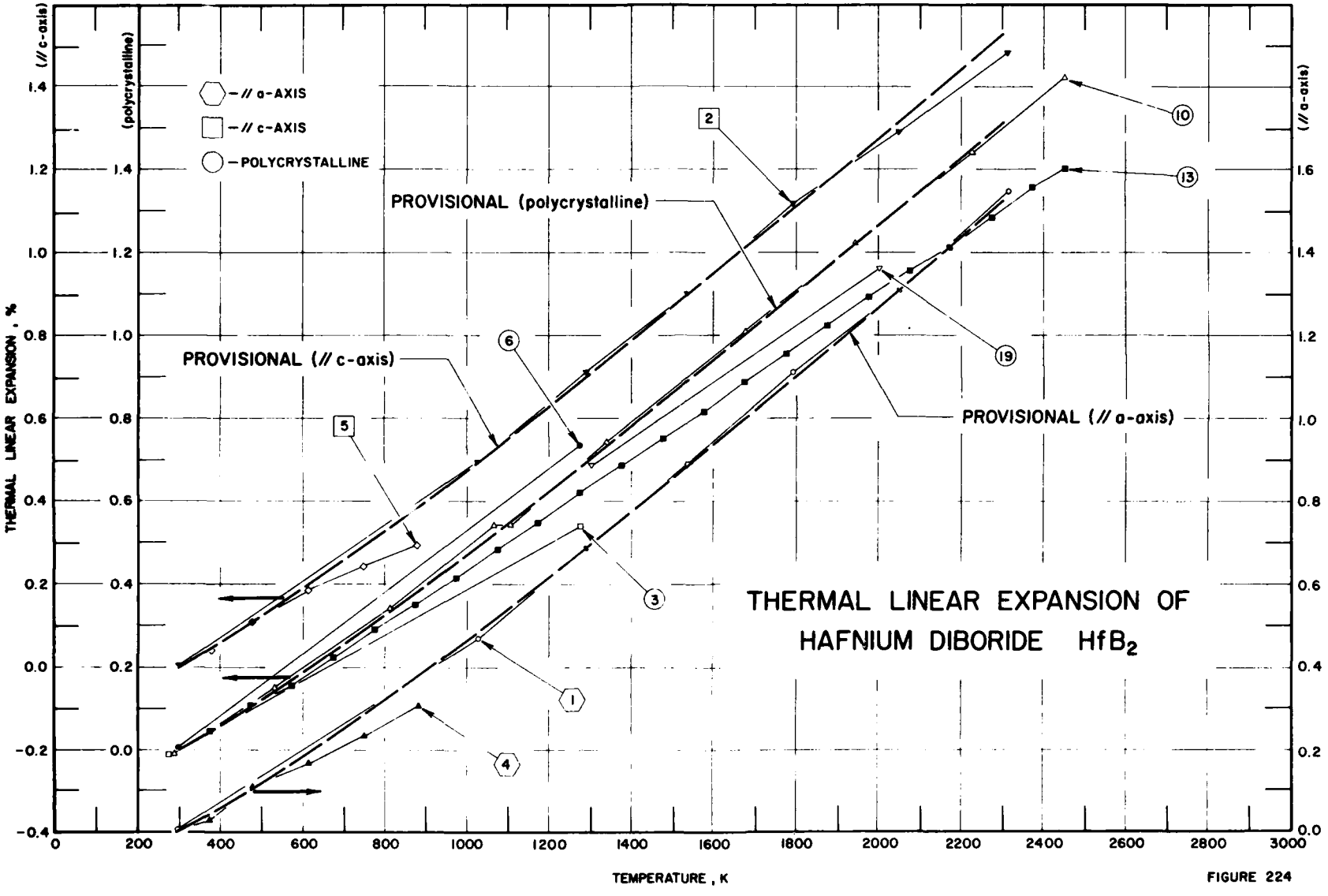

(// c-axis)
(polycrystalline)
(// a-axis)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
// a-AXIS
// c-AXIS
POLYCRYSTALLINE
PROVISIONAL (polycrystalline)
PROVISIONAL (// c-axis)
PROVISIONAL (// a-axis)
THERMAL LINEAR EXPANSION OF
HAFNIUM DIBORIDE HfB_2
1
2
3
4
5
6
10
13
19

FIGURE 224

SPECIFICATION TABLE 224. THERMAL LINEAR EXPANSION OF HAFNIUM DIBORIDE HfB_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	467	Keihn, F.G. and Keplin, E.J.	1967	X	298-2314	V-161	Specimen of hexagonal structure; 87.05 Hf, 10.86 B, 1.73 Zr, 0.21 O, 0.07 C, 0.04 Fe, 0.012 N, 0.007 Cu, 0.005 Si, 0.005 Ti, 0.003 Cr, 0.0005 Mn, and 0.00005 Mg; high-purity powder specimen having average size of 7 μ, cold-pressed into briquet; nickel-filtered CuK radiation used; lattice parameter along a-axis determined by measuring the 2 θ values for (200) and (300) planes; lattice parameter reported at 298 K as 3.1426 Å; 3.1425 Å at 293 K determined by graphical extrapolation.
2	467	Keihn, F.G. and Keplin, E.J.	1967	X	298-2314	V-161	The above specimen; expansion measured along c-axis; lattice parameter determined by measuring 2 θ value for (104) or (203) planes; lattice parameter reported at 298.3 K as 3.4780 Å; 3.4779 Å at 293 K determined by graphical extrapolation.
3	3	Steele, S.R., Pappis, J., Schilling, H., and Hagen, L.	1967		273,1273		Specimen deposited from the vapor at 2173 K.
4	468	American Electro Metal Corp.	1955	X	300-881		Powder specimen sprinkled on heater which served as holder; expansion along a-axis by measuring interplanar spacing for (110) line; interplanar spacing reported at 300 K as 1.5732 Å; 1.5732 Å at 293 K determined by graphical extrapolation.
5	468	American Electro Metal Corp.	1955	X	298-878		The above specimen; expansion along c-axis by measuring interplanar spacing for (002) line; interplanar spacing reported at 298 K as 1.7409 Å; 1.7409 Å at 293 K determined by graphical extrapolation.
6	469	Kaufman, L. and Clougherty, E.V.	1965	L	298,1273		89.33 Hf, 10.73 B_2, 0.04 C, 0.02 O, 0.01 N, 0.001 Fe, single crystal hexagonal structure specimen formed by floating zone melt method; 90% of theoretical density; expansion measured along a-axis; reported error ± 5%.
7*	469	Kaufman, L. and Clougherty, E.V.	1965	L	298,1273		88.3 Hf, 10.5 B, fully dense polycrystalline specimen formed by hot-pressing at 300,000 psi at high temperature 2073-2273 K; 90% at theoretical density, data reported as polycrystalline; reported error ± 5%.
8*	470	Keihn, F.G.	1963	X	298-2314		Expansion measured along a-axis from (200), (300), and (104) planes using Siemens x-ray diffractometer; zero-point correction of 0.003% determined by graphical extrapolation; lattice parameter reported at 298 K as 3.1426 Å.
9*	470	Keihn, F.G.	1963	X	298-2314		The above specimen; expansion measured along c-axis; zero-point correction of 0.003% determined by graphical extrapolation; lattice parameter reported at 298 K as 3.4780 Å.
10	63	Pears, C.D. and Oglesby, S.	1962		283-2878		89.5 Hf, 10.0 B, 0.01 C; initial length 2.222 in.; Carborundum Co.; elements found by semi-quantitative emission spectrography before exposure 0.1 Mg, 0.1 Ti, 3.5 Fe, and 1.5 Zr, after exposure 89.4 Hf, 10.5 B, and 0.77 C; hot pressed; specimen melted at 2872 K; density in g cm^{-3} at 298 K before exposure 10.7 by ASTM method B311-58, 10.7 by wax-coating specimen, 10.8 by immersion in xylene, after exposure 10.1 by ASTM method, 10.2 by wax-coating specimen, 10.3 by immersion in xylene; expansion measured in helium atmosphere; reported error 5%; zero-point correction of -0.01% determined by graphical interpolation.

* Not shown in figure.

SPECIFICATION TABLE 224. THERMAL LINEAR EXPANSION OF HAFNIUM DIBORIDE HfB_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
11*	443	Bernstein, H.	1964	X	1073, 1773	$HfB_{(1.97)}$	Specimen powder sifted through 200 mesh screen and deposited as thin slurry directly on tantalum heater strips (heater strips annealed at 1773 K for several hr prior to use); expansion measured along a-axis; expansion measured under pressure of 1-2 x 10^{-5} mm Hg; lattice parameter of a-axis reported at 293 K as 3.1410 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
12*	443	Bernstein, H.	1964	X	1073, 1773	$HfB_{(1.97)}$	The above specimen; expansion measured along c-axis; lattice parameter of c-axis reported at 293 K as 3.4761 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
13	612	Samsonov, G.V., Kovenshaya, B.A., Serebryakova, T.L., and Tel'nikov, E. Ya.	1970	L	273-2448		89.0 Hf, 10.8 B_2, and 0.1 other; specimen made by hot compaction method; zero-point correction is -0.017%; reported error 1.5% in temperature range 300 to 1300 K and 5-7% in temperature range 1300 to 2500 K.
14*	613	Lécrivoin, V.L. and Provost, G.	1968		273-2129		93.04 Hf, 7.06 B_2; specimen formed by plasma spraying; curve represents theoretical expansion of specimen; zero-point correction is -0.03%.
15*	613	Lécrivoin, V.L. and Provost, G.	1968		273-2129		The above specimen untreated (not annealed); sprayed material during heating phase; zero-point correction is -0.03%.
16*	613	Lécrivoin, V.L. and Provost, G.	1968		2129-273		The above specimen; expansion measured with decreasing temperature; zero-point correction is -0.03%.
17*	613	Lécrivoin, V.L. and Provost, G.	1968		273-2125		Same as curve 16, annealed at 2273 K; zero-point correction is -0.23%.
18*	726	Samsonov, G.V., Bolgar, A.S., Kovenskaya, B.A., Guseua, E.A., Serebrykavo, T.I., Klockhov, L.A., Turchanin, A.G., and Fesenko, V.V.	1973	X	300, 1300		No details given.
19	726	Samsonov, G.V., et al.	1973	X	1300, 2000		No details given.

* Not shown in figure.

DATA TABLE 224. THERMAL LINEAR EXPANSION OF HAFNIUM DIBORIDE HfB_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
298	0.0031
1026	0.4677
1287	0.6873
1536	0.8910
1790	1.1105
2043	1.3078
2314	1.5433

CURVE 2

T	$\Delta L/L_0$
298	0.0028
1026	0.4974
1287	0.7101
1536	0.8999
1790	1.1127
2043	1.2852
2314	1.4807

CURVE 3

T	$\Delta L/L_0$
273	-0.011
1273	0.539

CURVE 4

T	$\Delta L/L_0$
300	0.0000*
377	0.0254
478	0.1080
612	0.1652
746	0.2351
881	0.3051

CURVE 5

T	$\Delta L/L_0$
298	0.0000*
377	0.0402
476	0.1091
611	0.1838
746	0.2412
878	0.2929

CURVE 6

T	$\Delta L/L_0$
298	0.004
1273	0.734

CURVE 7*

T	$\Delta L/L_0$
298	0.004
1273	0.753

CURVE 8*

T	$\Delta L/L_0$
298	0.003
1026	0.474
1287	0.687
1536	0.891
1790	1.110
2043	1.304
2314	1.546

CURVE 9*

T	$\Delta L/L_0$
298	0.003
1026	0.498
1287	0.710
1536	0.900
1790	1.113
2043	1.280
2314	1.481

CURVE 10

T	$\Delta L/L_0$
283	-0.01
532	0.15
812	0.34
1063	0.54
1103	0.54
1338	0.74
1675	1.01
1939	1.22
2222	1.44
2448	1.62
2608	2.53*
2667	2.76*
2835	3.00*
2835	4.00*
2848	5.79*
2878	7.57*
2878	7.70*

CURVE 11*,†

T	$\Delta L/L_0$
1073	0.000
1773	0.465

CURVE 12*,†

T	$\Delta L/L_0$
1073	0.000
1773	0.482

CURVE 13

T	$\Delta L/L_0$
273	-0.017*
293	0.000*
373	0.047
473	0.107
573	0.154
673	0.222
773	0.290
873	0.351
973	0.414
1073	0.481
1173	0.548
1273	0.621
1373	0.686
1473	0.751
1573	0.815
1673	0.885
1773	0.954
1873	1.021
1973	1.089
2073	1.154
2173	1.213
2273	1.284
2373	1.356
2448	1.403

CURVE 14*

T	$\Delta L/L_0$
273	-0.03
293	0.00
373	0.06
473	0.12
573	0.19
673	0.28
773	0.34
873	0.40

CURVE 14 (cont.)*

T	$\Delta L/L_0$
973	0.48
1073	0.57
1173	0.64
1273	0.71
1373	0.77
1473	0.85
1573	0.92
1673	0.98
1773	1.07
1873	1.13
1973	1.19
2073	1.26
2129	1.32

CURVE 15*

T	$\Delta L/L_0$
273	-0.03
293	0.00
373	0.03
473	0.10
573	0.13
673	0.19
773	0.25
873	0.30
923	0.32
973	0.38
1023	0.47
1073	0.53
1123	0.62
1173	0.71
1223	0.84
1273	1.11
1323	1.34
1373	1.56
1423	1.67
1473	1.80
1523	1.87
1573	1.91
1623	1.94
1673	1.92
1723	1.88
1773	1.73
1823	1.59
1873	1.46
1923	1.41

CURVE 15 (cont.)*

T	$\Delta L/L_0$
1973	1.35
2023	1.35
2073	1.39
2123	1.48
2129	1.54

CURVE 16*

T	$\Delta L/L_0$
2129	1.34
2073	1.29
1973	1.17
1873	1.08
1773	0.97
1673	0.90
1573	0.80
1473	0.74
1373	0.63
1273	0.61
1173	0.59
1073	0.52
973	0.46
873	0.39
773	0.32
673	0.25
573	0.17
473	0.11
373	0.04
293	0.00
273	-0.03

CURVE 17*

T	$\Delta L/L_0$
273	-0.03
293	0.00
373	0.06
473	0.12
573	0.17
673	0.24
773	0.31
873	0.39
973	0.47
1073	0.53
1173	0.60
1273	0.64
1373	0.72

CURVE 17 (cont.)*

T	$\Delta L/L_0$
1473	0.77
1573	0.86
1673	0.92
1773	1.01
1873	1.08
1973	1.15
2073	1.18
2125	1.19

CURVE 18*

T	$\Delta L/L_0$
300	0.004
1300	0.634

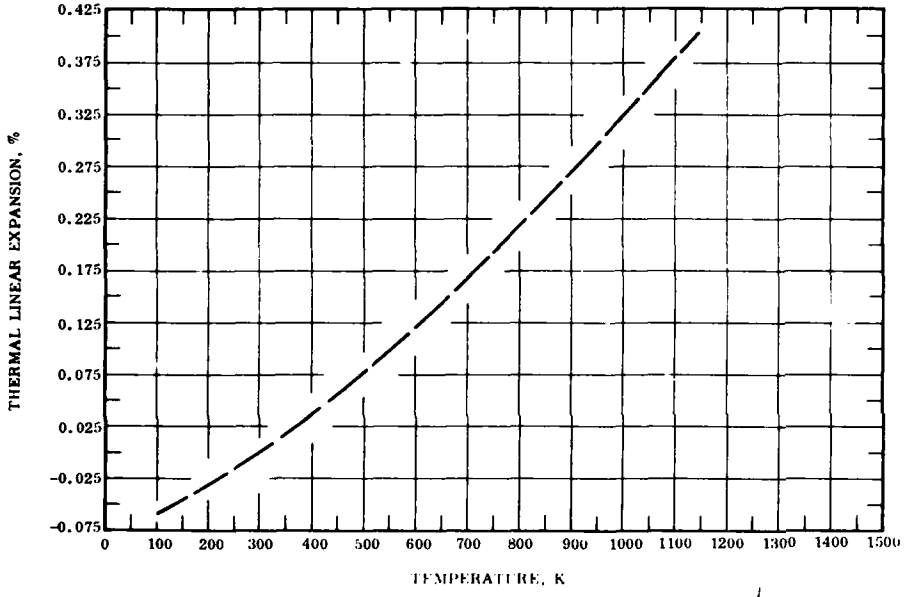
CURVE 19

T	$\Delta L/L_0$
1300	0.684
2000	1.160

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

FIGURE AND TABLE NO. 225R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF HOLMIUM DODECABORIDE HoB_{12}



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
100	-0.057	2.6
150	-0.044	2.8
200	-0.030	3.0
250	-0.014	3.2
293	0.000	3.4
350	0.020	3.6
400	0.039	3.8
500	0.079	4.2
600	0.122	4.5
700	0.169	4.8
800	0.218	5.1
900	0.270	5.3
1000	0.324	5.5
1100	0.379	5.6
1150	0.408	5.7

REMARKS

The provisional values are based on the data for the high purity sample from the recent measurements which follows the general trend for other dodecaborides. These values are considered accurate to within ±7% and are represented approximately by the following equation:

$$\Delta L/L_0 = -8.033 \times 10^{-2} + 2.041 \times 10^{-4}\ T + 2.555 \times 10^{-7}\ T^2 - 5.555 \times 10^{-11}\ T^3$$

The tabulated values for the coefficient of thermal expansion are primarily based on the selected experimental data. These values are considered accurate to about ±10%.

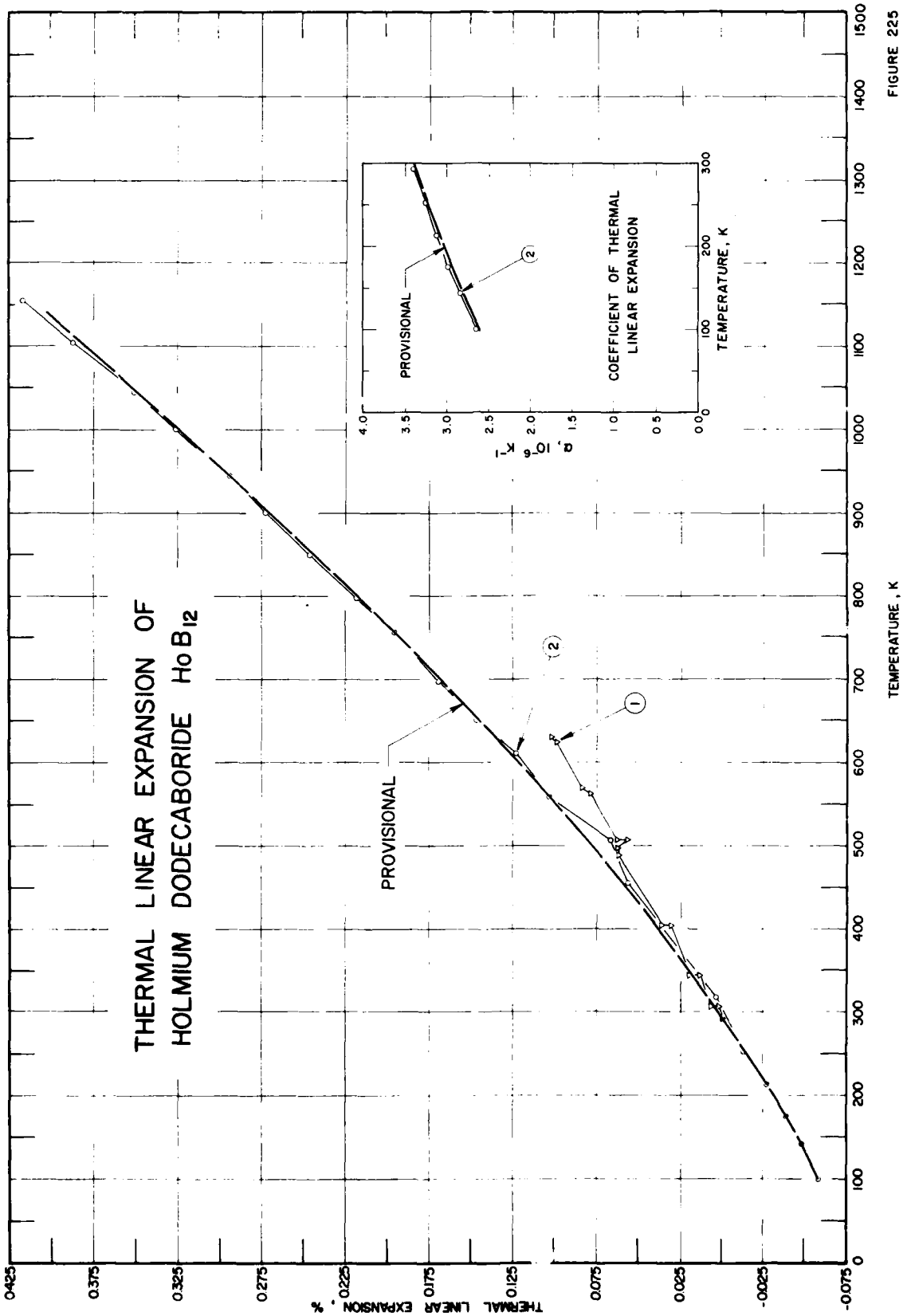

THERMAL LINEAR EXPANSION OF
HOLMIUM DODECABORIDE HoB12
PROVISIONAL
(1)
(2)
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
α, 10⁻⁶ K⁻¹
PROVISIONAL
(2)
TEMPERATURE, K

FIGURE 225

SPECIFICATION TABLE 225. THERMAL LINEAR EXPANSION OF HOLMIUM DODECABORIDE HoB_{12}

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	611	LaPlaca, S., Binder, I., and Post, B.	1961	X	293-628		Specimen face-centered-cubic structure; expansion measured using filtered Cu x-radiation.
2	610	Paderno, Yu.B., Odinstov, V.V., Timofeeva, I.I., and Klochkov, L.A.	1970	X/L	100-1163		Cylindrical specimens; dimensions 7 mm diameter x 10-12 mm long; made by vacuum reduction, then sintered in argon atmosphere at 2073-2173 K for 2 hr at 7465 kg/cm^2; x-ray method used from 13-300 K and dilatometer used from 300-1300 K.

DATA TABLE 225. THERMAL LINEAR EXPANSION OF HOLMIUM DODECABORIDE HoB_{12}

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 2 (cont.)	
293	0.000	100	-0.059	850	0.246
303	0.001	141	-0.048	900	0.272
303	0.006	173	-0.038	942	0.295
348	0.013	213	-0.026	1000	0.327
348	0.020	251	-0.014	1044	0.352
409	0.030	293	0.000*	1107	0.387
409	0.036	319	0.009	1163	0.418
489	0.061	456	0.061		
496	0.061	508	0.082		
508	0.055	559	0.104		
508	0.061	602	0.123		
564	0.077	651	0.146		
570	0.083	699	0.169		
624	0.098	754	0.196		
628	0.102	799	0.219		

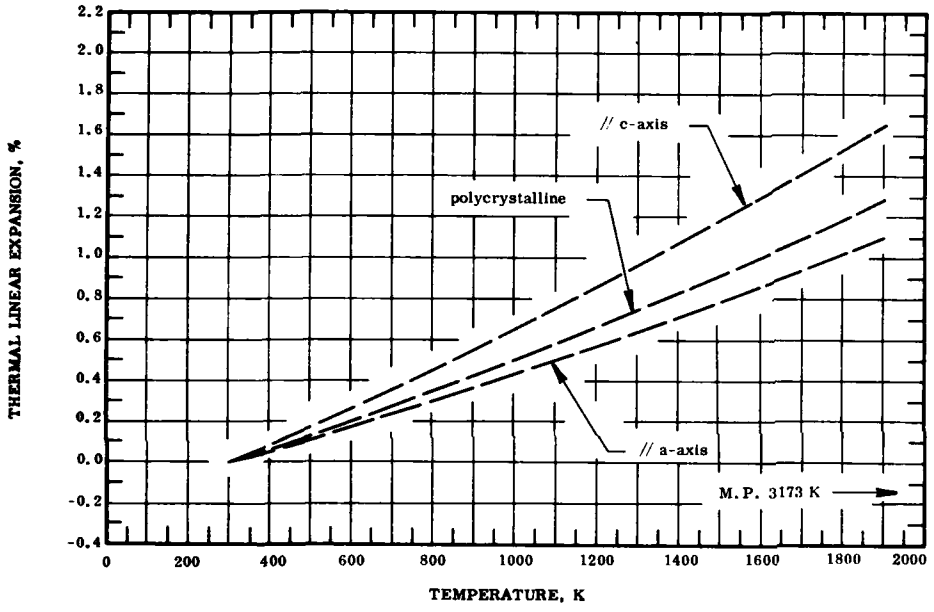
DATA TABLE 225. COEFFICIENT OF THERMAL LINEAR EXPANSION OF HOLMIUM DODECABORIDE HoB_{12}

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α
CURVE 2		CURVE 2 (cont.)	
100	2.64	799	5.15*
141	2.83	850	5.28*
173	2.98	900	5.40*
213	3.11	942	5.48*
251	3.26	1000	5.55*
293	3.41	1044	5.56*
319	3.51*	1107	5.55*
456	4.01*	1163	5.55*
508	4.20*		
559	4.39*		
602	4.54*		
651	4.73*		
699	4.89*		
754	5.04*		

* Not shown in figure.

FIGURE AND TABLE NO. 226R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF NIOBIUM DIBORIDE NbB_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	6.3
300	0.004	0.006	0.005	6.3
400	0.058	0.091	0.069	6.6
500	0.115	0.178	0.136	6.8
600	0.174	0.268	0.205	7.0
700	0.235	0.360	0.276	7.2
800	0.298	0.455	0.350	7.4
900	0.363	0.551	0.425	7.7
1000	0.430	0.650	0.503	7.9
1100	0.498	0.752	0.583	8.1
1200	0.569	0.856	0.664	8.2
1300	0.640	0.962	0.747	8.4
1400	0.714	1.070	0.832	8.6
1500	0.789	1.181	0.919	8.8
1600	0.865	1.294	1.008	9.0
1700	0.943	1.410	1.098	9.1
1800	1.022	1.528	1.191	9.3
1900	1.102	1.649	1.284	9.4

REMARKS

The provisional values for the axial thermal expansion are based on the data for powdered samples. The provisional values for the polycrystalline sample are derived from these values and are in fair agreement with the experimental data. The provisional values are considered accurate to within ±7% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.145 + 4.594 \times 10^{-4}\ T + 1.288 \times 10^{-7}\ T^2 - 1.324 \times 10^{-11}\ T^3$

// c-axis: $\Delta L/L_0 = -0.236 + 7.710 \times 10^{-4}\ T + 1.138 \times 10^{-7}\ T^2 + 1.269 \times 10^{-12}\ T^3$

polycrystalline: $\Delta L/L_0 = -0.175 + 5.620 \times 10^{-4}\ T + 1.241 \times 10^{-7}\ T^2 - 8.210 \times 10^{-12}\ T^3$

The tabulated values for the coefficient of thermal expansion are derived primarily by differentiating the above equation for the polycrystalline sample. These values are considered accurate to about ±10%.

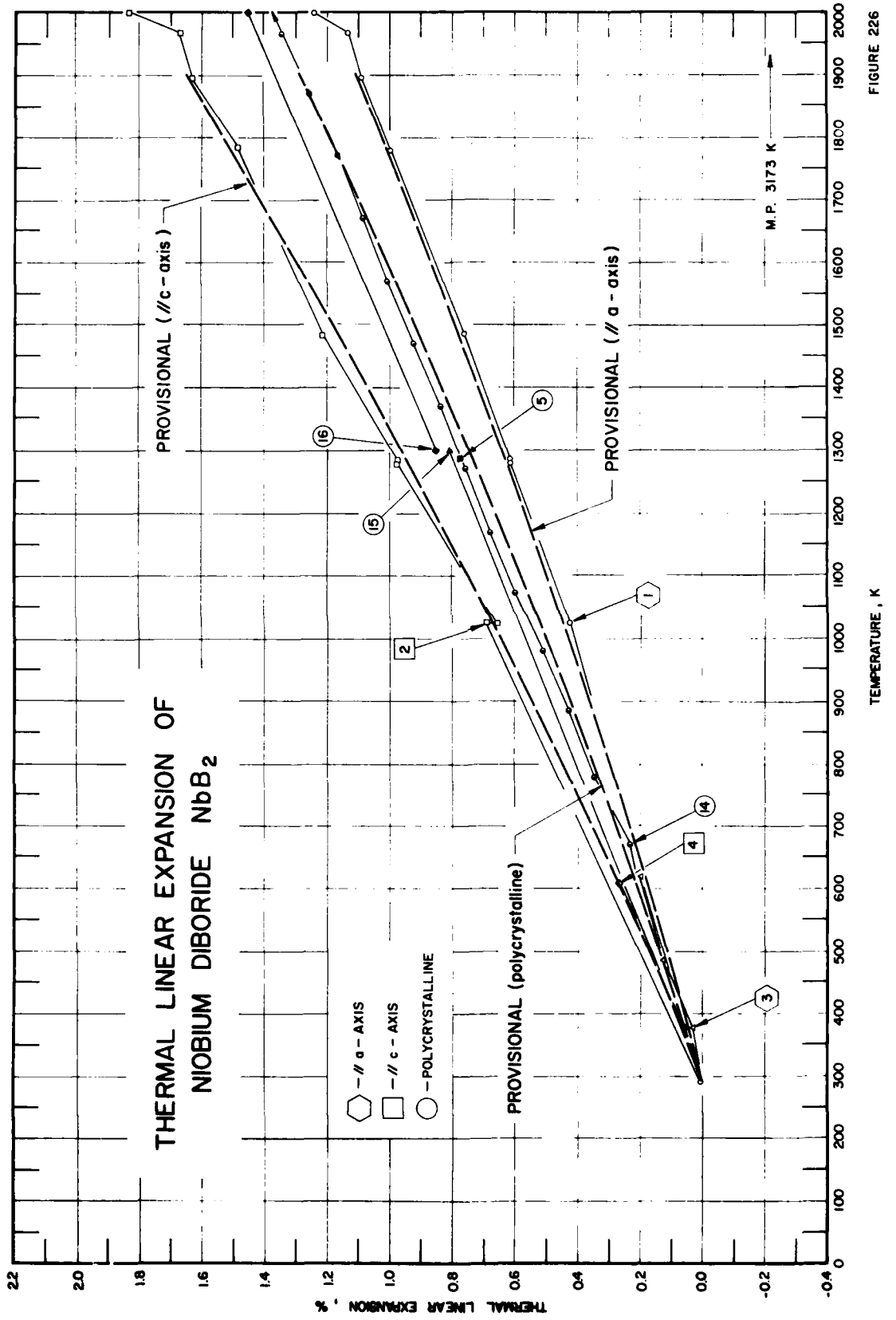

THERMAL LINEAR EXPANSION OF
NIOBIUM DIBORIDE NbB_2
PROVISIONAL (//c - axis)
PROVISIONAL (// a - axis)
PROVISIONAL (polycrystalline)
M.P. 3173 K
— // a - AXIS
— // c - AXIS
— POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 226

SPECIFICATION TABLE 226. THERMAL LINEAR EXPANSION OF NIOBIUM DIBORIDE NbB_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	467	Keihn, F.G. and Keplin, E.J.	1967	X	298-2000	V-219	Specimen of hexagonal structure; 73.66 Nb, 25.20 B, 0.22 Si, 0.077 O, 0.042 Fe, 0.03 Al, 0.03 Ti, 0.025 Ni, 0.02 each Ca, Mn, Cu, 0.002 Mg and 0.001 Cr; high-purity powder specimen having average size about 7 μ, cold-pressed into briquet; x-ray diffractometer operated in helium atmosphere; specimen prepared with excess boron; expansion measured along a-axis; lattice parameter reported at 298 K as 3.0866 Å; 3.0865 Å at 293 K determined by graphical extrapolation.
2	467	Keihn, F.G. and Keplin, E.J.	1967	X	298-2000	V-219	The above specimen; expansion measured along c-axis; lattice parameter reported at 298 K as 3.3084 Å; 3.3082 Å at 293 K determined by graphical extrapolation.
3	468	American Electro Metal Corp.	1955	X	299-614		Powder specimen sprinkled on heater which served as holder; expansion measured along a-axis; interplanar spacing reported at 299 K as 1.5551 Å; 1.5551 Å at 293 K determined by graphical extrapolation.
4	468	American Electro Metal Corp.	1955	X	299-610		The above specimen; expansion measured along c-axis; interplanar spacing reported at 299 K as 1.6379 Å; 1.6378 Å at 293 K determined by graphical extrapolation.
5	469	Kaufman, L. and Clougherty, E.V.	1965	L	298,1273		81.42 Nb, 18.47 B_2, 0.01 C, 0.006 O, 0.005 N, 0.0001 Fe, single crystal; rod; had considerable crack formation, specimen formed by floating zone melt method; data reported as polycrystalline.
6*	443	Bernstein, H.	1964	X	1073,1773	$NbB_{(1.72-2.27)}$	Specimen powder sifted through 200 mesh screen and deposited as thin acetone slurry directly on tantalum heater strips (heater strips annealed at 1773 K for several hr prior to use); expansion measured along a-axis; expansion measured under pressure of 1-2 x 10^{-5} mm Hg; lattice parameter of a-axis reported at 293 K as 3.117 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
7*	443	Bernstein, H.	1964	X	1073,1773	$NbB_{(1.72-2.27)}$	The above specimen; expansion measured along c-axis; lattice parameter of c-axis reported at 293 K as 3.261 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
8*	443	Bernstein, H.	1964	X	1073,1773	$NbB_{(1.99)}$	Similar to the above specimen; expansion measured along a-axis; lattice parameter of a-axis reported at 293 K as 3.107 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
9*	443	Bernstein, H.	1964	X	1073,1773	$NbB_{(1.99)}$	The above specimen; expansion measured along c-axis; lattice parameter of c-axis reported at 293 K as 3.282 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
10*	443	Bernstein, H.	1964	X	1073,1773	$NbB_{(1.94)}$	Similar to the above specimen; expansion measured along a-axis; lattice parameter of a-axis reported at 293 K as 3.1085 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
11*	443	Bernstein, H.	1964	X	1073,1773	$NbB_{(1.94)}$	The above specimen; expansion measured along c-axis; lattice parameter of c-axis reported at 293 K as 3.263 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
12*	443	Bernstein, H.	1964	X	1073,1773	$NbB_{(1.87)}$	Similar to the above specimen; expansion measured along a-axis; lattice parameter of a-axis reported at 293 K as 3.109 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

SPECIFICATION TABLE 226. THERMAL LINEAR EXPANSION OF NIOBIUM DIBORIDE NbB_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
13*	443	Bernstein, H.	1964	X	1073, 1773	$NbB_{(1.87)}$	The above specimen; expansion measured along c-axis; lattice parameter of c-axis reported at 293 K as 3.264 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
14	612	Samsonov, G.V., Kovenskaya, B.A., Serebryakova, T.L., and Tel'nikov, E.Ya.	1970	L	273-2305		80.2 Nb, 19.8 B_2, specimen formed by hot compaction method; reported error was 1.5% for 300-1300 K range and 5-7% for 1300-2500 K range; zero-point correction is -0.0179% determined by graphical extrapolation.
15	726	Samsonov, G.V., Bolgor, A.S., Harenskaya, B.A., Guseva, E.A., Serebyhavo, T.I., Klochkhov, L.A., Turchanin, A.G., and Fesenko, V.V.	1973	X	300, 1300		No details given.
16*	726	Samsonov, G.V., et al.	1973	X	1300, 2000		No details given.

* Not shown in figure.

DATA TABLE 226. THERMAL LINEAR EXPANSION OF NIOBIUM DIBORIDE NbB_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

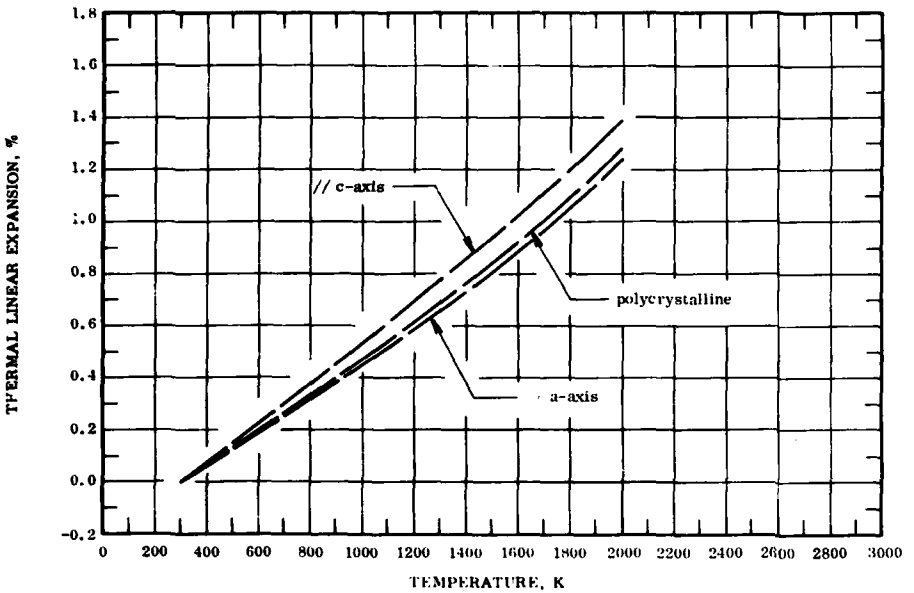
T	$\Delta L/L_0$
CURVE 1	
296	0.0032
1026	0.4244
1280	0.6155
1285	0.6155
1483	0.7743
1483	0.7678
1787	0.9978
1787	1.0076
1898	1.0918
1969	1.1372
2000	1.2441
CURVE 2	
298	0.0060*
1026	0.6952
1026	0.6589
1280	0.9733
1285	0.9733
1483	1.2091
1483	1.1909
1787	1.4872
1787	1.5023
1898	1.6232
1969	1.6595
2000	1.8318
CURVE 3	
299	0.0000*
380	0.0321
477	0.1286
614	0.1929
CURVE 4	
299	0.0061*
377	0.0549
477	0.1343
610	0.2686
CURVE 5	
298	0.004
1273	0.772

T	$\Delta L/L_0$
CURVE 6*, †	
1073	0.000
1773	0.608
CURVE 7*, †	
1073	0.000
1773	0.659
CURVE 8*, †	
1073	0.000
1773	0.608
CURVE 9*, †	
1073	0.000
1773	0.659
CURVE 10*, †	
1073	0.000
1773	0.608
CURVE 11*, †	
1073	0.000
1773	0.659
CURVE 12*, †	
1073	0.000
1773	0.608
CURVE 13*, †	
1073	0.000
1773	0.659
CURVE 14	
273	-0.017*
293	0.000*
373	0.047*
473	0.107*
573	0.194

T	$\Delta L/L_0$
CURVE 14 (cont.)	
673	0.266
773	0.344
873	0.421
973	0.502
1073	0.596
1173	0.676
1273	0.758
1373	0.839
1473	0.925
1573	1.012
1673	1.086
1773	1.171
1873	1.256
1973	1.338
2073	1.424
2173	1.502
2273	1.585
2305	1.604
CURVE 15	
300	0.005*
1300	0.805
CURVE 16*	
1300	0.855
2000	1.450

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

FIGURE AND TABLE NO. 227R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF TANTALUM DIBORIDE TaB_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	6.5
350	0.037	0.041	0.038	6.5
400	0.069	0.078	0.072	6.6
500	0.132	0.151	0.138	6.6
600	0.195	0.225	0.205	6.7
700	0.257	0.300	0.271	6.7
800	0.319	0.375	0.338	6.8
900	0.382	0.451	0.405	6.8
1000	0.446	0.529	0.474	6.9
1100	0.511	0.607	0.543	7.1
1200	0.579	0.687	0.615	7.3
1300	0.649	0.768	0.689	7.5
1400	0.721	0.851	0.765	7.7
1500	0.797	0.935	0.843	8.0
1600	0.877	1.020	0.925	8.3
1700	0.960	1.108	1.010	8.6
1800	1.049	1.198	1.099	9.1
1900	1.142	1.289	1.191	9.5
2000	1.241	1.383	1.288	10.0

REMARKS

The provisional values for the axial expansion are based on the data for powdered specimens. The provisional values for polycrystalline sample are calculated from these values. The experimental data reported for hot pressed material and with high tantalum content are about 8% higher. The provisional values are considered accurate to within ±10%, and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.200 + 7.203 \times 10^{-4} T - 1.485 \times 10^{-7} T^2 + 7.427 \times 10^{-11} T^3$

// c-axis: $\Delta L/L_0 = -0.212 + 7.226 \times 10^{-4} T - 9.364 \times 10^{-10} T^2 + 1.924 \times 10^{-11} T^3$

polycrystalline: $\Delta L/L_0 = -0.204 + 7.203 \times 10^{-4} T - 9.783 \times 10^{-8} T^2 + 5.537 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are derived primarily by differentiating the above equation for the polycrystalline sample. These values are considered accurate to about ±5%.

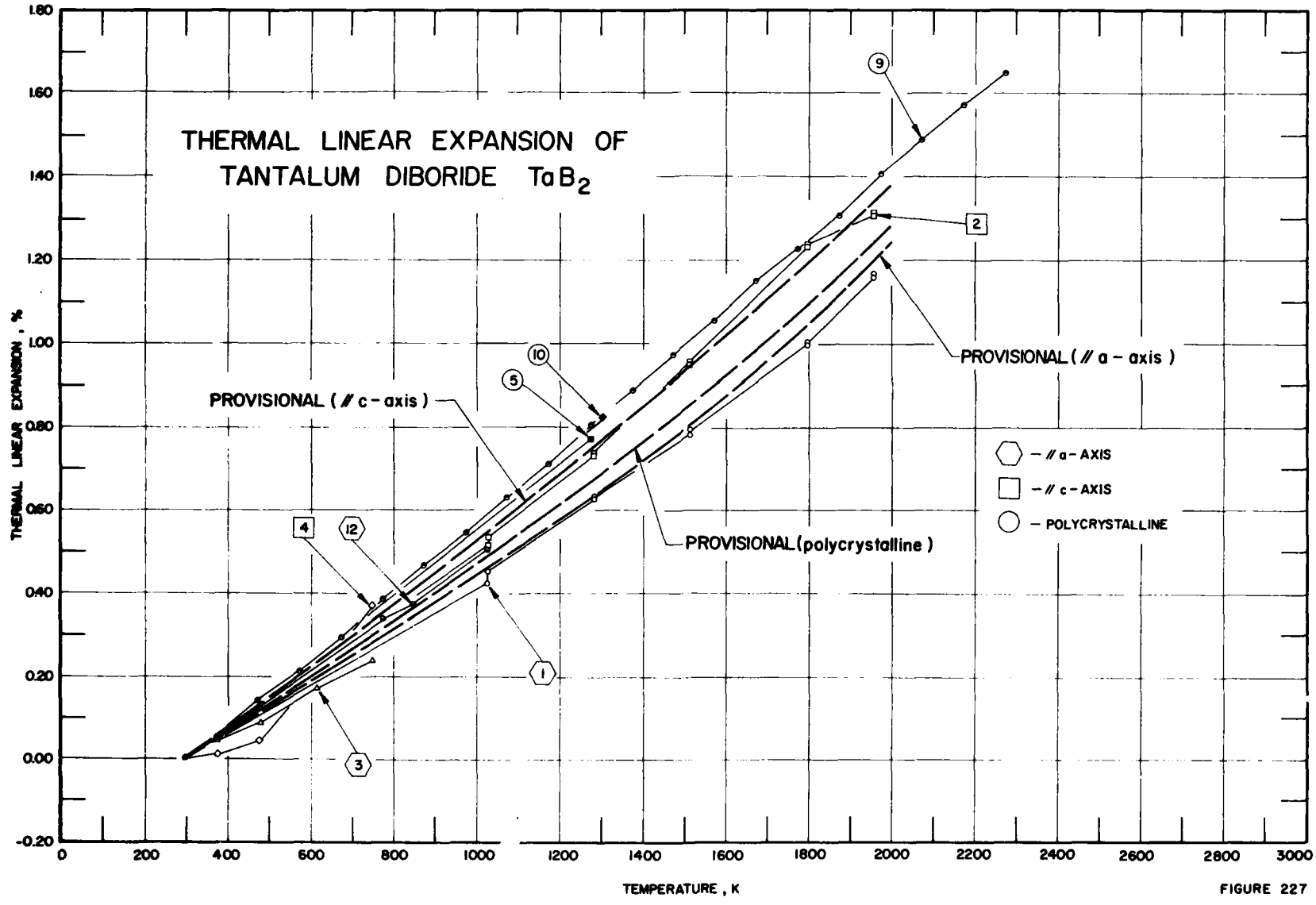

THERMAL LINEAR EXPANSION OF
TANTALUM DIBORIDE TaB_2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
PROVISIONAL (// c - axis)
PROVISIONAL (// a - axis)
PROVISIONAL (polycrystalline)
- // a - AXIS
- // c - AXIS
- POLYCRYSTALLINE
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000

FIGURE 227

SPECIFICATION TABLE 227. THERMAL LINEAR EXPANSION OF TANTALUM DIBORIDE TaB_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	467	Keihn, F.G. and Keplin, E.J.	1967	X	298-1954	L-38-138	Specimen of hexagonal structure; 79.86 Ta, 18.77 B, 0.43 Si, 0.17 Al, 0.089 O, 0.05 Ca, 0.03 Mn, 0.025 Ni, 0.01 Mg, Nb, 0.003 Cu, 0.001 Ag, Cr; high-purity powder specimen having average size of about 7 μ, cold-pressed into briquet; x-ray diffractometer operated in helium atmosphere; prepared with excess boron; expansion measured along a-axis; lattice parameter reported at 298 K as 3.0604 Å; 3.0603 Å at 293 K determined by graphical extrapolation.
2	467	Keihn, F.G. and Keplin, E.J.	1967	X	298-1954	L-38-138	The above specimen; expansion measured along c-axis; lattice parameter reported at 298 K as 3.2896 Å; 3.2895 Å at 293 K determined by graphical extrapolation.
3	468	American Electro Metal Corp.	1955	X	298-746		Powder specimen sprinkled on heater which served as holder; expansion measured along a-axis; interplanar spacing reported at 298 K as 1.5389 Å; 1.5389 Å at 293 K determined by graphical extrapolation.
4	468	American Electro Metal Corp.	1955	X	298-744		The above specimen; expansion measured along c-axis; interplanar spacing reported at 298 K as 1.6260 Å; 1.6260 Å at 293 K determined by graphical extrapolation.
5	469	Kaufman, L. and Clougherty, E.V.	1965	L	298,1273		88.80 Ta, 11.22 B_2, 0.02 C, 0.02 C_1, 0.003 O, 0.002 N, 0.001 Fe, hexagonal structure, cylinder, formed by hot pressing at 300,000 psi at high temperatures (2073-2273 K) 90% of theoretical density obtained.
6*	443	Bernstein, H.	1964	X	1073,1773	$TaB_{(1.98)}$	Specimen powders sifted through 200 mesh screen and deposited as thin acetone slurry directly on tantalum heater strips (heater strips annealed at 1773 K for several hr prior to use); expansion measured under pressure of $1-2 \times 10^{-5}$ mm Hg; expansion measured along a-axis; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$; lattice parameter of a-axis reported at 293 K as 3.085 Å.
7*	443	Bernstein, H.	1964	X	1073,1773	$TaB_{(1.95)}$	The above specimen; expansion measured along c-axis; lattice parameter of c-axis reported at 293 K as 3.240 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
8*	608	Samsonov, G.V., Vlasov, L.G., Grebenkina, V.G., Yusov, Yu.P., and Perevezentsev, A.V.	1971	X	82-3332		Sintered powder; data taken from smooth curve which authors generated from their two experimental points.
9	612	Samsonov, G.V., Kovenskaya, B.A., Serebryakeva, T.L., and Tel'nikov, E.Ya.	1970	L	273-2273		88.6 Ta, 10.9 B_2, 0.5 other specimen made by hot compaction method; error for 300-1300 K reported as 1.5% while from 1300-2500 K it was 5-7%; zero-point correction is -0.017%.
10*	726	Samsonov, G.V., Bolgar, A.S., Kovenskaya, B.A., Guseva, E.A., Serebryakeva, T.L., Klockhov, L.A., Turchanin, A.G., and Fesenko, V.V.	1973	X	300,1300		No details given.
11*	726	Samsonov, G.V., et al.	1973	X	1300,2000		No details given.

* Not shown in figure.

SPECIFICATION TABLE 227. THERMAL LINEAR EXPANSION OF TANTALUM DIBORIDE TaB_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
12	1029	Holleck, H., Benesovsky, F., Laube, E., and Nowotny, H.	1962	X	283-1143		Expansion measured along a-axis; lattice parameter reported at 283 K as 3.084 Å; 3.0845 Å at 293 K determined by graphical interpolation.
13*	1029	Holleck, H., et al.	1962	X	283-1143		Expansion measured along c-axis; lattice parameter reported at 283 K as 3.220 Å; 3.2206 Å at 293 K determined by graphical interpolation.

* Not shown in figure.

DATA TABLE 227. THERMAL LINEAR EXPANSION OF TANTALUM DIBORIDE TaB_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.0032
1026	0.4247
1026	0.4574
1280	0.6339
1280	0.6306
1513	0.7940
1513	0.7809
1797	1.0031
1797	0.9966
1954	1.1600
1954	1.1698
CURVE 2	
298	0.0030*
1026	0.5167
1026	0.5350
1280	0.7356
1280	0.7387
1513	0.9484
1513	0.9575
1797	1.2342
1797	1.2372
1954	1.3102
1954	1.3163
CURVE 3	
298	0.0000
377	0.0454
480	0.0909
614	0.1754
746	0.2404
CURVE 4	
298	0.012*
377	0.013
475	0.044
610	0.179*
744	0.370
CURVE 5	
298	0.004*
1273	0.772
CURVE 6*,†	
1073	0.000
1773	0.592
CURVE 7*,†	
1073	0.000
1773	0.763
CURVE 8*,‡	
82	-0.053
172	-0.036
250	-0.014
293	0.000
366	0.026
500	0.078
602	0.120
750	0.183
859	0.231
1000	0.296
1250	0.416
1500	0.543§
1750	0.678§
2000	0.821§
2250	0.970§
2500	1.127§
2750	1.290§
3000	1.460§
3250	1.637§
3332	1.697§
CURVE 9	
273	-0.017*
293	0.000*
373	0.068
473	0.141
573	0.217
673	0.298
773	0.384
873	0.464
973	0.544
1073	0.635
1173	0.715
1273	0.803
1373	0.887
CURVE 9 (cont.)	
1473	0.978
1573	1.057
1673	1.147
1773	1.238
1873	1.316
1973	1.403
2073	1.491
2173	1.573
2273	1.654
CURVE 10*	
300	0.006
1300	0.826
CURVE 11*	
1300	0.8861
2000	1.502
CURVE 12	
283	-0.016*
293	0.000*
773	0.340
850	0.373
1013	0.503
1143	0.827*
CURVE 13*	
283	-0.01553
293	0.000
773	0.574
850	0.606
1013	0.792
1143	1.164

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

§ Extrapolated values.

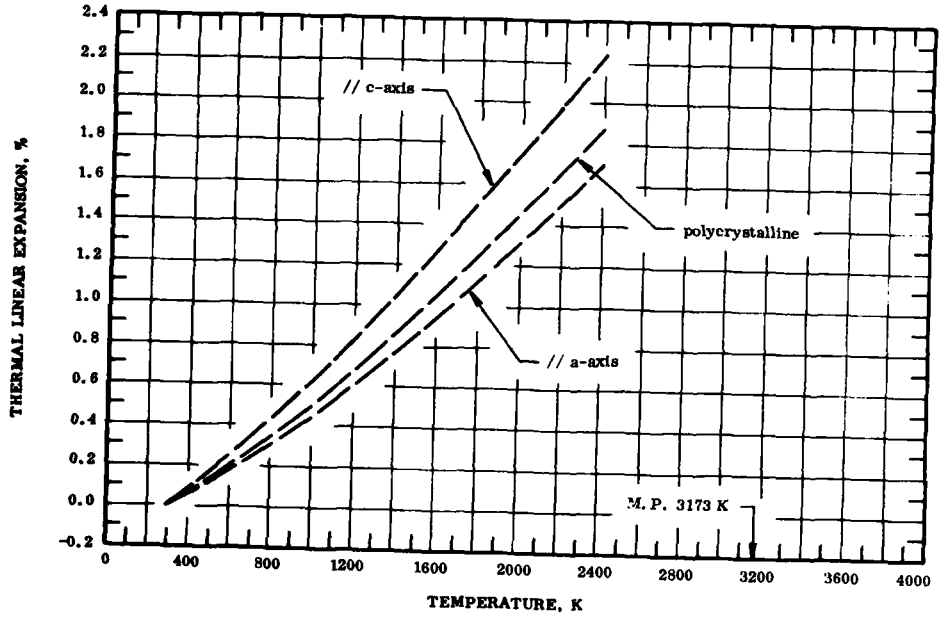
DATA TABLE 227. COEFFICIENT OF THERMAL LINEAR EXPANSION OF TANTALUM DIBORIDE TaB_2

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 8*,‡	
82	1.23
172	2.60
250	3.05
293	3.40
366	3.70
500	4.03
602	4.19
750	4.36
859	4.50
1000	4.67
1250	4.94
1500	5.25§
1750	5.54§
2000	5.85§
2250	6.13§
2500	6.40§
2750	6.64§
3000	6.95§
3250	7.22§
3332	7.38§

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.
§ Extrapolated values.

FIGURE AND TABLE NO. 228R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF TITANIUM DIBORIDE TiB_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	// a-axis $\Delta L/L_0$	// c-axis $\Delta L/L_0$	polycrystalline $\Delta L/L_0$	polycrystalline α
293	0.000	0.000	0.000	5.6
300	0.003	0.005	0.004	5.6
400	0.052	0.083	0.062	6.1
500	0.106	0.164	0.126	6.5
600	0.164	0.251	0.193	7.0
700	0.227	0.341	0.265	7.4
800	0.293	0.434	0.340	7.7
900	0.363	0.532	0.419	8.1
1000	0.436	0.632	0.501	8.4
1200	0.592	0.841	0.675	9.0
1400	0.759	1.060	0.859	9.4
1600	0.936	1.286	1.052	9.9
1800	1.119	1.518	1.252	10.2
2000	1.307	1.753	1.456	10.3
2200	1.499	1.989	1.662	10.4
2400	1.692	2.224	1.870	10.5

REMARKS

The provisional values for the axial thermal expansion are based on the data for powdered samples. The provisional values for the polycrystalline sample are derived from these values which agree with most of the experimental data. The provisional values are considered accurate to about ±7% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.114 + 3.092 \times 10^{-4}\, T + 2.806 \times 10^{-7}\, T^2 - 3.996 \times 10^{-11}\, T^3$

// c-axis: $\Delta L/L_0 = -0.197 + 5.959 \times 10^{-4}\, T + 2.770 \times 10^{-7}\, T^2 - 4.369 \times 10^{-11}\, T^3$

polycrystalline: $\Delta L/L_0 = -0.142 + 4.054 \times 10^{-4}\, T + 2.786 \times 10^{-7}\, T^2 - 4.097 \times 10^{-11}\, T^3$

The tabulated values for the coefficient of thermal expansion are derived primarily from differentiating the above equation for polycrystalline sample. These values are considered accurate to about ±10%.

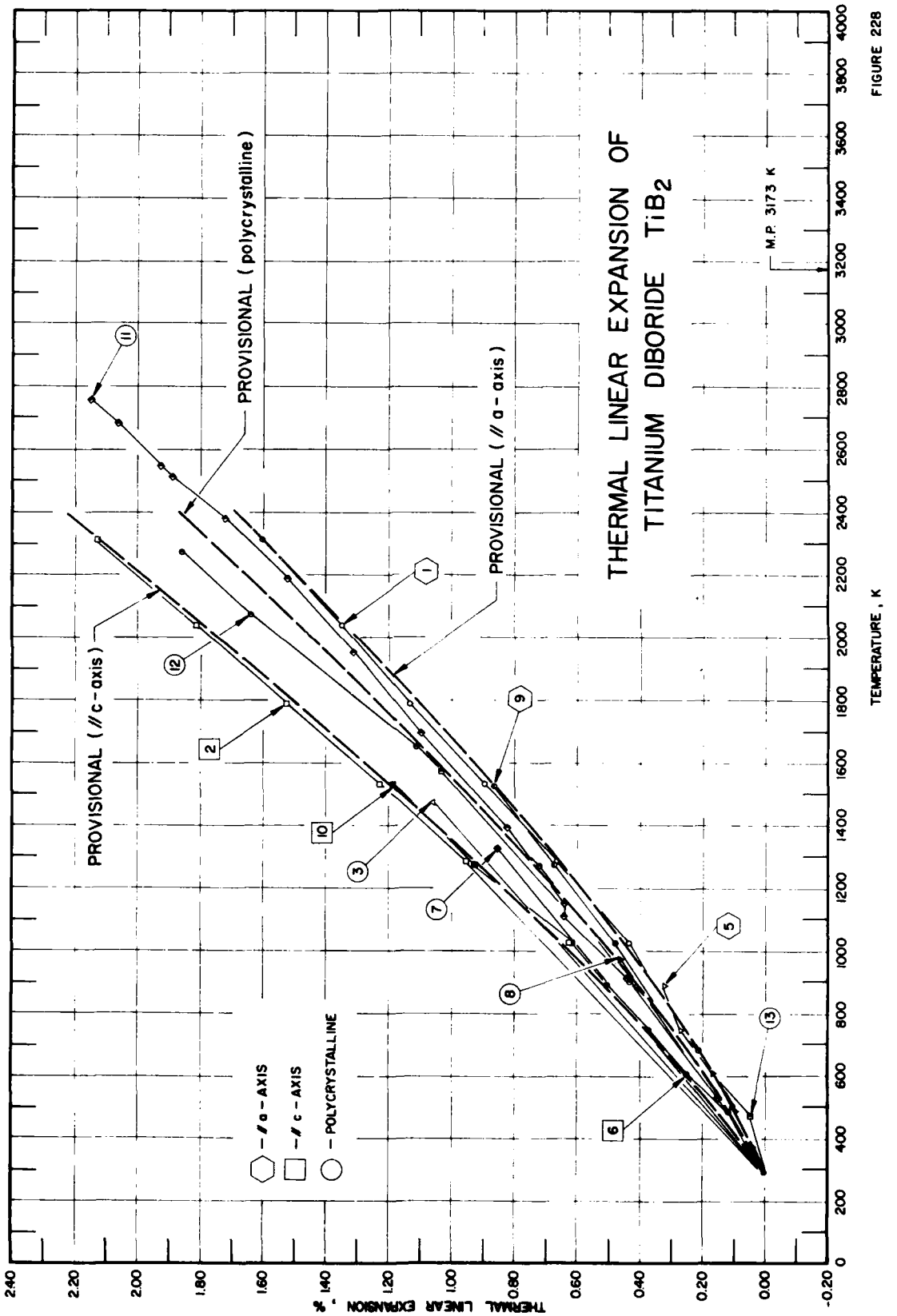

THERMAL LINEAR EXPANSION OF
TITANIUM DIBORIDE TiB_2
PROVISIONAL (polycrystalline)
PROVISIONAL (// a - axis)
PROVISIONAL (// c - axis)
M.P. 3173 K
// a - AXIS
// c - AXIS
POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K

FIGURE 228

SPECIFICATION TABLE 228. THERMAL LINEAR EXPANSION OF TITANIUM DIBORIDE TiB_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	467	Keihn, F.G. and Keplin, E.J.	1967	X	298-2314	V-126	Specimen of hexagonal structure; 68.50 Ti, 31.05 B, 0.147 O, 0.085 Fe, 0.07 C, 0.02 N, 0.01 Cu, 0.002 Al, 0.002 Cr, 0.001 Mn, 0.0006 Si, and 0.00005 Mg; high purity powder specimen having average size of about 7 μ; cold-pressed into briquets; lattice parameter determined by measuring the 2 θ values for (202) and (300) planes; expansion measured along a-axis; nickel-filtered CuK radiation used; lattice parameter reported at 298 K as 3.0286 Å; 3.0285 Å at 293 K determined by graphical extrapolation.
2	467	Keihn, F.G. and Keplin, E.J.	1967	X	298-2314	V-126	The above specimen; expansion measured along c-axis; lattice parameter determined by measuring the 2 θ values for (104) and (203) planes; lattice parameter reported at 298 K as 3.2282 Å; 3.2231 Å at 293 K determined by graphical extrapolation.
3	437	Frantsevich, I.N., Zhurakovshii, E.A. and Lyashchenko, A.B.	1967	X	293,1473		69.06 Ti, 30.2 B, and 0.3 C_{tot}; theoretical content of metalloid 31.1; sample prepared from powder by vacuum sintering of pressed block; hot-pressed.
4*	3	Steele, S.R., Pappis, J., Schilling, H., and Hagan, L.	1967		273,1273		Specimen deposited from a vapor at 1573-1623 K.
5	468	American Electro Metal Corp.	1955	X	298-884		Powder specimen sprinkled on heater which served as holder; expansion measured along a-axis; interplanar spacing reported at 293 K as 1.5170 Å; 1.5171 Å at 293 K determined by graphical extrapolation.
6	468	American Electro Metal Corp.	1955	X	293-885		The above specimen; expansion measured along c-axis; interplanar spacing reported at 293 K as 1.6180 Å; 1.6172 Å at 293 K determined by graphical extrapolation.
7	469	Kaufman, L. and Clougherty, E.V.	1965	L	298,1273		68.58 T_1, 30.64 B_2, 0.3 O, 0.07 Fe, 0.03 each C_1 and N_1 hexagonal crystal, powder specimen; reached in aqueous 6N HF at 373 K for 4 hr, then heated at 1748 K for 4 hr in vacuo (1×10^{-2} mm Hg), then hot-pressed at 300,000 psi at high temperatures 2073-2273 K; 93-99% of theoretical density obtained, reported error ± 5%.
8	471	Meerson, G.A., Samsonov, G.V., Kotel'nikov, R.B., Voinova, M.S., Evteeva, L.P., and Krasnenkova, S.D.	1958	L	293,973		Specimen 8 mm diameter, 15-20 mm high; prepared by sintering mixtures of boride powders by method of hot molding in graphite dye.
9	472	Lowrie, R.	1964	X	298-1523		Expansion measured along a-axis; lattice parameter reported at 298 K as 3.0293 Å; 3.0292 Å at 293 K determined by graphical extrapolation.
10	472	Lowrie, R.	1964	X	298-1523		Expansion measured along c-axis; lattice parameter reported at 298 K as 3.2288 Å; 3.2287 Å at 293 K determined by graphical extrapolation.
11	63	Pears, C.D. and Oglesby, S.	1962	L	289-2758		69.8 Ti, 29.5 B, 0.2 C, 0.6 N_2; initial length 2.271 in.; obtained from Carborundum Co.; elements found by semi-quantitative emission spectrography before exposure 0.3 V, 0.4 Fe, after exposure 69.3 Ti, 28.7 B, 0.32 C, and 0.3 N_2; hot pressed; specimen melted at 2756 K; run no. E7; density in g cm^{-3} at 298 K before exposure 4.52 by ASTM method B311-58, 4.51 by wax-coating specimen, 4.57 by immersion in xylene, after exposure 4.17 by ASTM method, 4.16 by wax-coating specimen, 4.23 by immersion in xylene; expansion measured in helium atmosphere; reported error 5%.
12	473	Mandorf, V., Hartwig, J., and Seldin, E.J.	1963	L	293-2273		Specimen dimension 0.5 x 0.5 x 5 in.; hot pressed and sintered; heated under argon in a horizontal 2.5 in. diameter graphite tube furnace.

* Not shown in figure.

SPECIFICATION TABLE 228. THERMAL LINEAR EXPANSION OF TITANIUM DIBORIDE TiB_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
13	474	National Carbon Co.	1959		298-1573		Specimen purity as high as 99.5; produced by reducing oxides of titanium and boron to extremely fine and uniform particle size; theoretical density as high as 99%.
14*	443	Bernstein, H.	1964	X	1073, 1773	$TiB_{(1.96-1.99)}$	Specimen powder sifted through 200 mesh screen and deposited as a thin acetone slurry directly on tantalum heater strips (heater strips annealed at 1773 K for several hr prior to use); expansion measured under pressure of 1-2 x 10^{-6} mm Hg; lattice parameter of a-axis reported at 293 K as 3.030 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$; expansion measured along a-axis.
15*	443	Bernstein, H.	1964	X	1073, 1773	$TiB_{(1.96-1.98)}$	The above specimen; expansion measured along c-axis; lattice parameter of c-axis reported at 293 K as 3.228 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
16*	443	Bernstein, H.	1964	X	1073, 1773	$TiB_{(1.98-2.00)}$	Similar to the above specimen; expansion measured along a-axis; lattice parameter of a-axis reported at 293 K as 3.030 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
17*	443	Bernstein, H.	1964	X	1073, 1773	$TiB_{(1.98-2.00)}$	The above specimen; expansion measured along c-axis; lattice parameter of c-axis reported at 293 K as 3.229 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
18*	608	Samsonov, G.V., Grebenkina, V.G., Yosov, Yu.P., Vlasov, L.G., and Perenvezentsev, A.V.	1971	X	82-3280		Sintered powder; data taken from smooth curve which authors generated from their two experimental points.
19*	612	Samsonov, G.V., Kovenskaya, B.A., Serebryakova, T.I., and Tel'nikov, E.Ya.	1970	L	273-2605		69.0 Ti, 31.2 Bi; specimen produced by hot compaction method; error reported from 300-1300 K was 1.5% and from 1300-2500 K; reported error was 5-7%.
20*	1027	Urban, C., Provost, G., and Bentz, G.	1970		293-1273		Projection of specimen in nitrogen via plasma spraying as a powder; particle size was 10-60 μ.
21*	726	Samsonov, G.V., Bolgar, A.S., Guseva, E.A., Kovenskaya, B.A., Klockhov, L.A., Tarchanin, A.G., and Fesenko, V.V.	1973	X	300, 1300		No details given.
22*	726	Samsonov, G.V., et al.	1973	X	1300, 2000		No details given.

* Not shown in figure.

DATA TABLE 228. THERMAL LINEAR EXPANSION OF TITANIUM DIBORIDE TiB_2

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %)

T	$\Delta L/L_0$
CURVE 1	
298	0.0033
1027	0.4391
1285	0.6636
1533	0.8915
1787	1.1358
2040	1.3505
2314	1.6047
CURVE 2	
298	0.0030*
1027	0.6226
1285	0.9541
1533	1.2298
1787	1.5272
2040	1.8184
2314	2.1312
CURVE 3	
293	0.000*
1473	1.062
CURVE 4*	
273	-0.011
1273	0.539
CURVE 5	
293	0.000
299	0.007
367	0.046
486	0.099
608	0.171
744	0.270
884	0.323
CURVE 6	
293	0.000
295	0.000
378	0.049
486	0.111
609	0.241
743	0.365
885	0.494
CURVE 7	
298	0.004*
1273	0.815
CURVE 8	
293	0.000*
973	0.462
CURVE 9	
298	0.0033*
1023	0.4819
1273	0.6734
1523	0.8649
CURVE 10	
298	0.0030*
1023	0.6163
1273	0.9291
1523	1.1862
CURVE 11	
289	-0.003*
532	0.151
912	0.443
1110	0.641
1151	0.641
1395	0.821
1693	1.099
1954	1.313
2186	1.522
2380	1.724
2516	1.890
2546	1.926
2681	2.062
2758	2.150
CURVE 12	
293	0.000*
503	0.103
683	0.215
903	0.440
1273	0.720
CURVE 12 (cont.)	
1653	1.110
2078	1.640
2273	1.860
CURVE 13	
298	0.001*
473	0.045
1573	1.037
CURVE 14*, †	
1073	0.000
1773	0.503
CURVE 15*, †	
1073	0.000
1773	0.684
CURVE 16*, †	
1073	0.000
1773	0.503
CURVE 17*, †	
1073	0.000
1773	0.684
CURVE 18*	
82	-0.054
172	-0.036
250	-0.014
293	0.000
391	0.038
500	0.087
612	0.141
750	0.213
853	0.269
1000	0.354
1250	0.507
1500	0.671§
1750	0.845§
2000	1.030§
CURVE 18 (cont.)*	
2250	1.224§
2500	1.429§
2750	1.643§
3000	1.868§
3250	2.102§
3280	2.131§
CURVE 19*	
273	-0.01
293	0.000
373	0.015
473	0.041
573	0.070
673	0.103
773	0.139
873	0.171
973	0.217
1073	0.257
1173	0.305
1273	0.353
1373	0.401
1473	0.455
1573	0.502
1673	0.554
1773	0.603
1873	0.647
1973	0.697
2073	0.747
2173	0.795
2273	0.849
2373	0.900
2473	0.946
2573	0.993
2605	1.019
CURVE 20*	
293	0.000
323	0.021
373	0.051
423	0.080
473	0.112
523	0.146
573	0.186
623	0.228
CURVE 20 (cont.)*	
673	0.274
723	0.326
773	0.382
823	0.439
873	0.499
923	0.557
973	0.617
1023	0.674
1073	0.729
1123	0.784
1173	0.840
1223	0.899
1273	0.954
CURVE 21*	
300	0.003*
1300	0.463
CURVE 22*	
1300	0.523
2000	0.887

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

§ Extrapolated values.

SPECIFICATION TABLE 229. THERMAL LINEAR EXPANSION OF VANADIUM DIBORIDE VB_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	460	American Electro Metal Corp.	1955	X	293-889		Lattice parameter expansion measured along a-axis; lattice parameter reported at 297 K as 1.4949 Å; 1.4948 Å at 293 K determined by graphical extrapolation.
2*	460	American Electro Metal Corp.	1955	X	293-884		Lattice parameter expansion measured along c-axis; lattice parameter reported at 295 K as 1.5287 Å; 1.5286 Å at 293 K determined by graphical extrapolation.
3*	612	Samsonov, G.V., Kovenskaya, B.A., Serebryakova, T.L., and Tel'nikov, E.Ya.	1970	L	273-2273		70.1 V, 29.6 B, 0.3 other specimen formed by hot compaction method; error reported from 300-1300 K was 1.5% and from 1300-2500 K error was 5-7%; zero-point correction is -0.017%.
4*	726	Samsonov, G.V., Bolgar, A.S., Guseno, E.A., Klockhov, L.A., Fesenko, V.V., Korenskaya, B.A., Serebrykavo, T.I., and Turchanin, A.G.	1973	X	300, 1300		No details given.
5*	726	Samsonov, G.V., et al.	1973	X	1300, 2000		No details given.

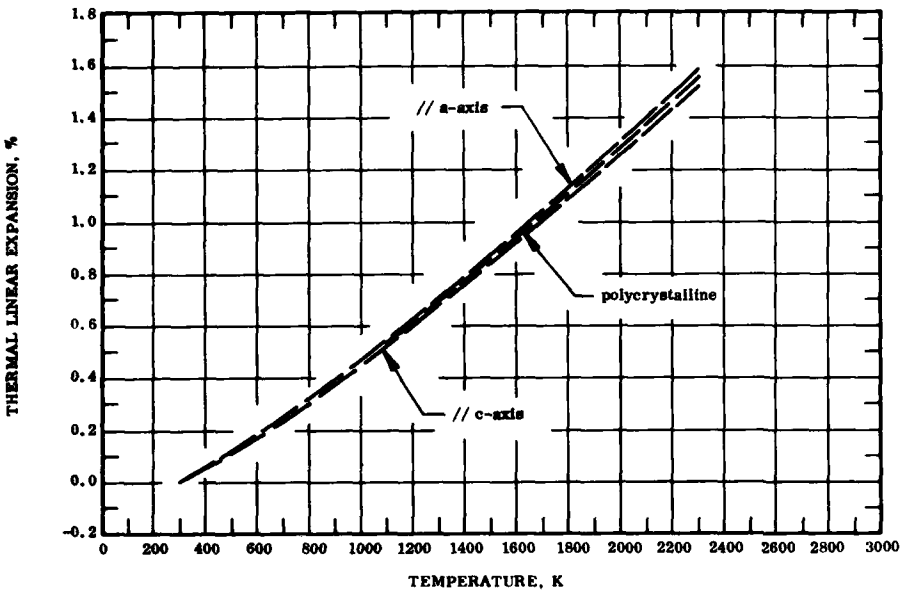
DATA TABLE 229. THERMAL LINEAR EXPANSION OF VANADIUM DIBORIDE VB_2

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %)

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
300	0.020
381	0.033
490	0.073
608	0.140
747	0.220
889	0.293
CURVE 2*	
293	0.000
296	0.007
381	0.124
489	0.275
745	0.576
884	0.896
CURVE 3*	
273	-0.017
293	0.000
373	0.057
473	0.121
573	0.188
673	0.262
773	0.332
873	0.403
973	0.481
1073	0.569
1173	0.648
1273	0.726
1373	0.808
1473	0.896
1573	0.973
1673	1.051
1773	1.135
CURVE 3 (cont.)*	
1873	1.219
1973	1.297
2073	1.372
2173	1.451
2273	1.529
CURVE 4*	
300	0.005
1300	0.765
CURVE 5*	
1300	0.835
2000	1.416

* No figure given.

FIGURE AND TABLE NO. 230R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ZIRCONIUM DIBORIDE ZrB_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	5.2
300	0.004	0.004	0.004	5.3
400	0.059	0.056	0.058	5.7
500	0.119	0.112	0.117	6.0
600	0.182	0.172	0.179	6.4
700	0.248	0.236	0.244	6.7
800	0.318	0.302	0.313	7.0
900	0.390	0.372	0.384	7.3
1000	0.465	0.444	0.458	7.5
1200	0.622	0.595	0.613	8.0
1400	0.787	0.754	0.776	8.3
1600	0.957	0.918	0.944	8.5
1800	1.131	1.087	1.116	8.7
2000	1.308	1.257	1.291	8.8
2200	1.484	1.427	1.465	8.9
2300	1.571	1.512	1.551	8.9

REMARKS

The provisional values for the axial thermal expansion are based on the data for powdered samples. The provisional values for polycrystalline sample are derived from these values. The experimental data reported for hot pressed samples (curves 12, 21, 23, and 24) are up to 20% lower at higher temperatures. The provisional values are considered accurate to within ±7% and can be approximately represented by the following equations:

// a-axis: $\Delta L/L_0 = -0.138 + 4.043 \times 10^{-4} T + 2.386 \times 10^{-7} T^2 - 3.969 \times 10^{-11} T^3$

// c-axis: $\Delta L/L_0 = -0.128 + 3.703 \times 10^{-4} T + 2.421 \times 10^{-7} T^2 - 4.046 \times 10^{-11} T^3$

polycrystalline: $\Delta L/L_0 = -0.135 + 3.940 \times 10^{-4} T + 2.390 \times 10^{-7} T^2 - 3.976 \times 10^{-11} T^3$

The tabulated values for the thermal expansion coefficient are primarily derived by differentiating the above equation for the polycrystalline sample. These values are considered accurate to about ±10%.

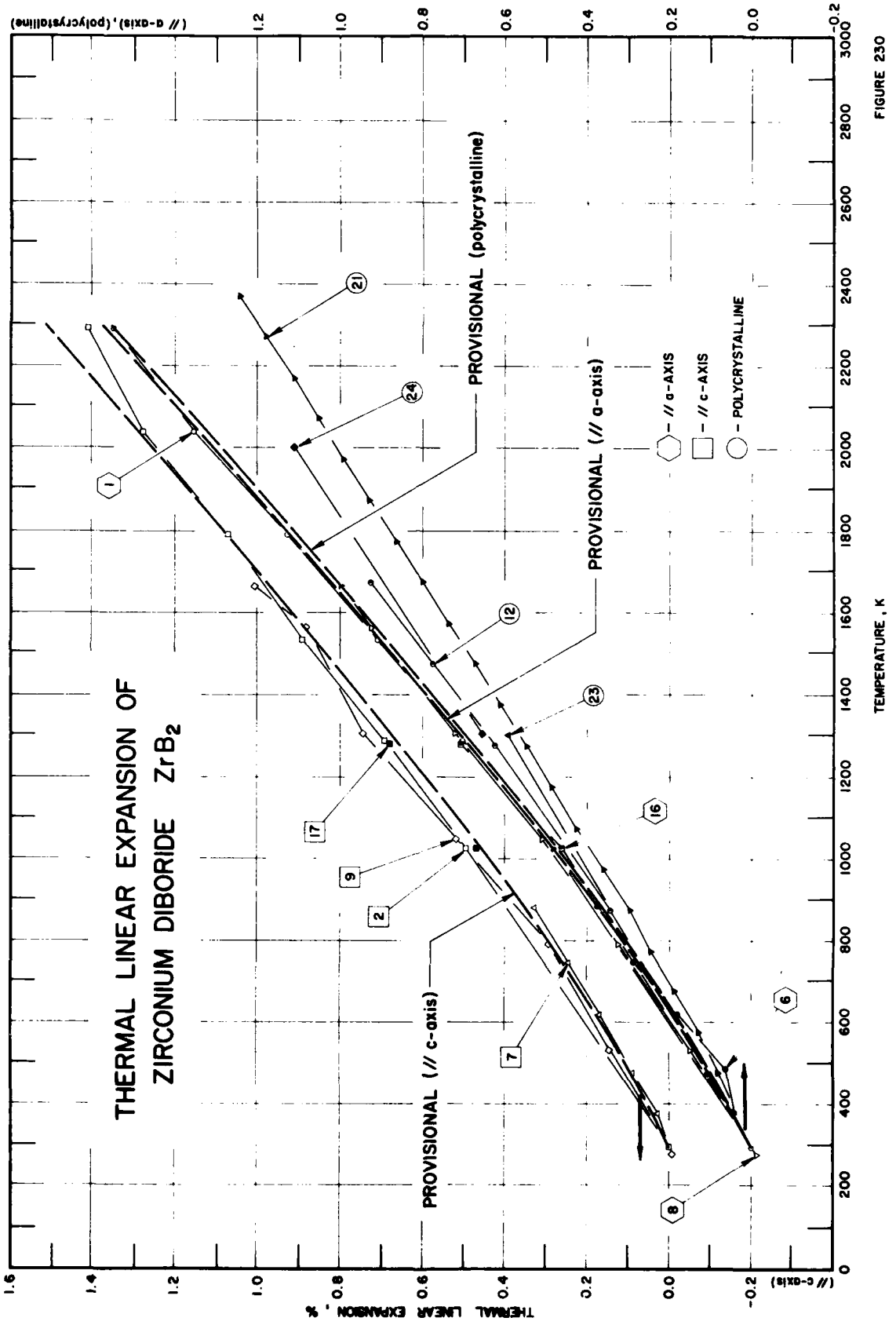

THERMAL LINEAR EXPANSION OF
ZIRCONIUM DIBORIDE ZrB_2
PROVISIONAL (polycrystalline)
PROVISIONAL (// a-axis)
PROVISIONAL (// c-axis)
- // a-AXIS
- // c-AXIS
- POLYCRYSTALLINE
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
(// c-axis)
(// a-axis), (polycrystalline)

FIGURE 230

SPECIFICATION TABLE 230. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIBORIDE ZrB_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	467	Keihn, F.G. and Keplin, E.J.	1967	X	298-2293	V-125	Specimen of hexagonal structure; 80.81 Zr, 19.26 B, 0.076 Cr, 0.06 C, 0.05 Fe, 0.04 N, 0.028 O, 0.01 T, 0.004 Al, 0.001 Si, 0.0004 Mn, and 0.0002 Mg; high purity powder specimen having average size of about 7 μ; cold-pressed into briquet; lattice parameter determined by measuring the 2θ value for the (202) and (300) planes; expansion measured along a-axis; nickel-filtered CuK radiation used; lattice parameter reported at 298 K as 3.1679 Å; 3.1678 Å at 293 K determined by graphical extrapolation.
2	467	Keihn, F.G. and Keplin, E.J.	1967	X	298-2293	V-125	The above specimen; expansion measured along c-axis; lattice parameter determined by measuring the 2θ values for the (104) or (203) planes; lattice parameter reported at 298 K as 3.5294 Å; 3.5293 Å at 293 K determined by graphical extrapolation.
3*	437	Frantsevich, I.N., Zhurakovshii, E.A., and Lyashchenko, A.B.	1967	X	293,1473		Sample prepared from powder by the vacuum sintering of pressed block; hot pressed.
4*	3	Steele, S.R., Pappis, J., Schilling, H., and Hagan, L.	1967		273,1273		Specimen deposited from a vapor at 1923-2123 K.
5*	475	Ault, G.M. and Deutsch, G.C.	1954		297-1477		Binder added; specimen density 5.2-5.4 g cm^{-3}.
6	468	American Electro Metal Corp.	1955	X	301-884		Powder specimen sprinkled on heater which served as holder; expansion measured along a-axis; interplanar spacing reported at 301 K as 1.5845 Å; 1.5844 Å at 293 K determined by graphical extrapolation.
7	468	American Electro Metal Corp.	1955	X	297-880		The above specimen; expansion measured along c-axis; interplanar spacing reported at 297 K as 1.7644 Å; 1.7644 Å at 293 K determined by graphical extrapolation.
8	10	Mauer, F.A. and Bolz, L.H.	1957	X	273-1663		Pure specimen with about 4.0 Hf showed by x-ray spectrographic analysis; hexagonal crystal structure in powder; sintered 30 min at 1400 C; expansion measured in vacuum along a-axis; lattice parameter reported at 273 K as 3.1674 Å; zero-point correction of -0.013% determined by graphical interpolation.
9	10	Mauer, F.A. and Bolz, L.H.	1957	X	273-1663		The above specimen; expansion measured along c-axis; lattice parameter reported at 273 K as 3.5298 Å; zero-point correction of -0.009% determined by graphical interpolation.
10*	469	Kaufman, L. and Clougherty, E.V.	1965	L	298, 1323		80.46 Zr, 18.82 B_2, 0.47 O, 0.16 C, 0.05 N, 0.03 Fe; single crystal rods surrounded by coarse grain edge; sample leveled in aqueous GN HF at 393 K for 4 hr hot pressed at 300,000 psi and at high temperatures (2073-2273 K) reported error ± 5%.
11*	471	Meerson, G.A., Samsonov, G.V., Kotel'nikov, R.B., Voinova, M.S., Evteeva, I.P., and Krasnenkova, S.D.	1958	L	293,973		Specimen 8 mm diameter, 15-20 mm high; prepared by sintering powders by m method of hot molding in graphite die.
12	476	Shaffer, P.T.B.	1962	L	473-1673		Specimen of -325 mesh powder, roll milled, hot pressed for 15 min at 2323 K and 2000-3000 psi; expansion measured in argon atmosphere.

* Not shown in figure.

SPECIFICATION TABLE 230. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIBORIDE ZrB_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
13*	318	Neel, D.S., Pears, C.D., and Oglesby, S., Jr.	1962	L	293-1393		78.0 Zr, 18.9 B, before exposure 0.58 C, 0.1 N, elements found by semi-quantitative emission spectrography 0.8 Fe, 0.3 Cr, 0.1 Ca, and 0.1 others, after exposure 78.6 Zr, 17.3 B, <0.1 N, and 0.57 C; initial length 2.9470 in., length 2.9450 in.; Norton Co.; hot pressed; Run SRI-E3; density in g cm^{-3} at 298 K before exposure 5.62 by ASTM method B311-58, 5.75 by wax-coating specimen, 5.69 by immersion in xylene, after exposure 5.44 by ASTM method, 5.46 by wax-coating specimen, and 5.60 by immersion in xylene; expansion measured in helium atmosphere; reported error 2%.
14*	318	Neel, D.S., et al.	1962	L	293-2410		Second exposure of SRI-E3; initial length 2.9450 in., final length 2.9463 in.; Run SRI-E4.
15*	318	Neel, D.S., et al.	1962	L	293-2783		Final exposure of SRI-E3; initial length 2.9463 in., final length 2.9416 in.; Run SRI-E21.
16	477	Houska, C.R.	1963	X	298-1278	Lot No. V-125	80.81 Zr, 19.26 B, 0.06 C, 0.04 N, 0.028 O, 0.01 Ti; powder specimen, approximately 50% dense, 0.125 x 0.50 x 4 in. in dimensions; lines (200) and (300) used to position diffraction surface and measure a-axis; average values of six runs at 298 K, 4 runs at 1023 K, 3 runs at 1278 K; lattice parameter reported at 298 K as 3.1677 Å; 3.1676 Å at 293 K determined by graphical extrapolation.
17	477	Houska, C.R.	1963	X	298-1278	Lot No. V-125	The above specimen; line (104) used to measure c-axis; lattice parameter reported at 298 K as 3.5295 Å; 3.5294 Å at 293 K determined by graphical extrapolation.
18*	443	Bernstein, H.	1964	X	1073, 1773	$ZrB_{(1.87-1.89)}$	Specimen powders sifted through 200 mesh screen and deposited as a thin acetone slurry directly on the tantalum heater strips (heater strips annealed at 1773 K for several hrs prior to use); expansion measured under pressure of $1-2 \times 10^{-5}$ mm Hg; lattice parameter of a-axis reported at 293 K as 3.171 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$; expansion measured along a-axis.
19*	443	Bernstein, H.	1964	X	1073, 1773	$ZrB_{(1.87-1.89)}$	The above specimen; lattice parameter of c-axis reported at 293 K as 3.572 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$; expansion measured along c-axis.
20*	608	Samsonov, G.V., Grebenkina, V.G., Yusov, Yu.P., Vlasov, L.G., and Perevezentsev, A.V.	1971	X	82-3308		Sintered powder; data taken from smooth curve which authors generated from their two experimental points.
21	612	Samsonov, G.V., Kovenskaya, B.A., Serebiyakova, T.L., and Tel'nikov, E.Ya.	1970	L	273-2373		80.3 Zr, 19.1 B_1 (*combined*), 0.1 B_2 (free), 0.5 others; specimen formed by the hot compaction method; error from 300-1300 K was 1.5% and from 1300-2500 K error was 5-7%; zero-point correction is -0.017%.
22*	1027	Urban, C., Provost, G., and Bentz, G.	1968		293-1273		Powder specimen projected in a plasma spray on graphite support in a nitrogen atmosphere heating phase.
23	726	Samsonov, G.V., Bolgar, A.S., Guseva, E.A., Klockhov, L.A., Turchanin, A.G., Kovenskaya, B.A., Serebrykavo, T.I., and Fesenko, V.V.	1973	X	300, 1300		No details given.
24	726	Samsonov, G.V., et al.	1973	X	1300, 2000		No details given.

*Not shown in figure.

DATA TABLE 230. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIBORIDE ZrB_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.0031
1027	0.4829
1285	0.7039
1533	0.9123
1787	1.1269
2040	1.3574
2293	1.5499
CURVE 2	
298	0.0028
1027	0.4958
1285	0.6970
1533	0.8953
1787	1.0738
2040	1.2778
2293	1.4082
CURVE 3*	
293	0.000
1473	0.767
CURVE 4*	
273	-0.011
1273	0.539
CURVE 5*	
297	0.002
811	0.252
1477	0.682
CURVE 6	
301	0.0063*
380	0.0441
482	0.0631
619	0.1830
745	0.2903
884	0.3786
CURVE 7	
297	0.0000*
377	0.0283
475	0.0906
615	0.1756
743	0.2493
880	0.3343
CURVE 8	
273	-0.013*
298	0.003*
531	0.151
788	0.325
1046	0.512
1303	0.723
1561	0.922
1663	0.998
CURVE 9	
273	-0.009
298	0.002*
531	0.149
788	0.297
1046	0.520
1303	0.747
1561	0.882
1663	1.007
CURVE 10*	
298	0.003
1323	0.818
CURVE 11*	
293	0.00
973	0.57
CURVE 12‡	
473	0.107
873	0.345
1273	0.624
1473	0.774
1673	0.927
CURVE 13*	
293	0.00
500	0.04
561	0.07
667	0.12
685	0.14
664	0.13
809	0.18
837	0.20
945	0.25
1129	0.34
1177	0.38
1251	0.42
1365	0.49
1393	0.51
CURVE 14*	
293	0.00
1088	0.34
1180	0.43
1288	0.50
1355	0.51
1383	0.53
1472	0.57
1566	0.68
1649	0.72
1738	0.79
1855	0.86
2088	0.96
2077	0.97
2116	1.00
2255	1.07
2410	1.09
2410	1.05
CURVE 15*	
293	0.00
1088	0.40
1238	0.49
1477	0.65
1688	0.78
2027	1.00
2227	1.14
2377	1.25
2547	1.35
CURVE 15 (cont.)*	
2661	1.39
2688	1.38
2783	1.33
CURVE 16	
298	0.0032*
1023	0.4609
1278	0.7008
CURVE 17	
298	0.0028*
1023	0.4675
1278	0.6800
CURVE 18*,†	
1073	0.000
1773	0.414
CURVE 19*,†	
1073	0.000
1773	0.493
CURVE 20*	
82	-0.058
168	-0.041
250	-0.016
293	0.000
361	0.029
500	0.095
593	0.144
750	0.231
862	0.297
1000	0.382
1100	0.446
1250	0.545
1500	0.719§
1750	0.906§
2000	1.103§
2250	1.311§
2500	1.529§
2750	1.758§
CURVE 20 (cont.)*	
3000	1.997§
3250	2.247§
3308	2.306§
CURVE 21	
273	-0.017*
293	0.000*
373	0.040*
473	0.082
573	0.131
673	0.191
773	0.246
873	0.299
973	0.360
1073	0.424
1173	0.484
1273	0.546
1373	0.613
1473	0.670
1573	0.739
1673	0.800
1773	0.863
1873	0.929
1973	0.992
2073	1.053
2173	1.112
2273	1.179
2373	1.243*
CURVE 22*	
293	0.00
323	0.12
373	0.34
423	0.55
473	0.89
523	1.26
573	1.63
623	2.04
673	2.49
723	2.94
773	3.39
823	3.88
873	4.33
923	4.83
CURVE 22 (cont.)*	
973	5.32
1023	5.78
1073	6.30
1123	6.76
1173	7.27
1223	7.75
1273	8.25
CURVE 23	
300	0.004*
1300	0.594
CURVE 24	
1300	0.554
2000	1.109

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.
§ Extrapolated values.

DATA TABLE 230. COEFFICIENT OF THERMAL LINEAR EXPANSION OF ZIRCONIUM DIBORIDE ZrB_2

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 12*,‡	
473	5.36
873	6.55
1273	7.38
1473	7.59
1673	7.70
CURVE 20*,‡	
82	1.23
168	2.70
250	3.45
293	3.95
361	4.44
500	5.10
593	5.41
750	5.71
862	6.01
1000	6.30
1100	6.52
1250	6.70
1500	7.25
1750	7.68
2000	8.12
2250	8.50
2500	8.96
2750	9.36
3000	9.77
3250	10.18
3308	10.33

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 231. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIBORIDE + MOLYBDENUM DISILICIDE + ΣX_i $ZrB_2 + MoSi_2 + \Sigma X_i$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	1014	Anthony, F.M.	1964		293-2033		81.1 ZrB_2, 13.0 $MoSi_2$, 5.9 B_4C; materials 97.5+ pure, blended dry 30 min., pressed with binder at 5000 psi, cured 24 hr at 436 K, set on high density Si_4C foam, fired 7 hr at 2498 to 2518 K in pure argon atmosphere.
2*	1015	Logan, I.M. and Niesse, J.E.	1962		293-2243		86.1 ZrB_2, 12.8 $MoSi_2$, 1.1 BN; dimension 3 in. by 0.5 in. by 0.25 in.; sintered; average value of several runs; average density 4.873 g cm^{-3}; measured in argon.
3*	1015	Logan, I.M. and Niesse, J.E.	1962		293-2243		86.1 ZrB_2, 12.8 $MoSi_2$, 1.1 BN; dimension 3 in. by 0.5 in. by 0.25 in.; hot pressed at 2188 K; average value of several runs; average density 5.48 g cm^{-3}; measured in argon.
4*	1015	Logan, I.M. and Niesse, J.E.	1962		293-1938		86.1 ZrB_2, 12.8 $MoSi_2$, 1.1 BN; dimension 3 in. by 0.25 in.; hot pressed; fabricated by using different lots of ZrB_2; average value of 3 runs.

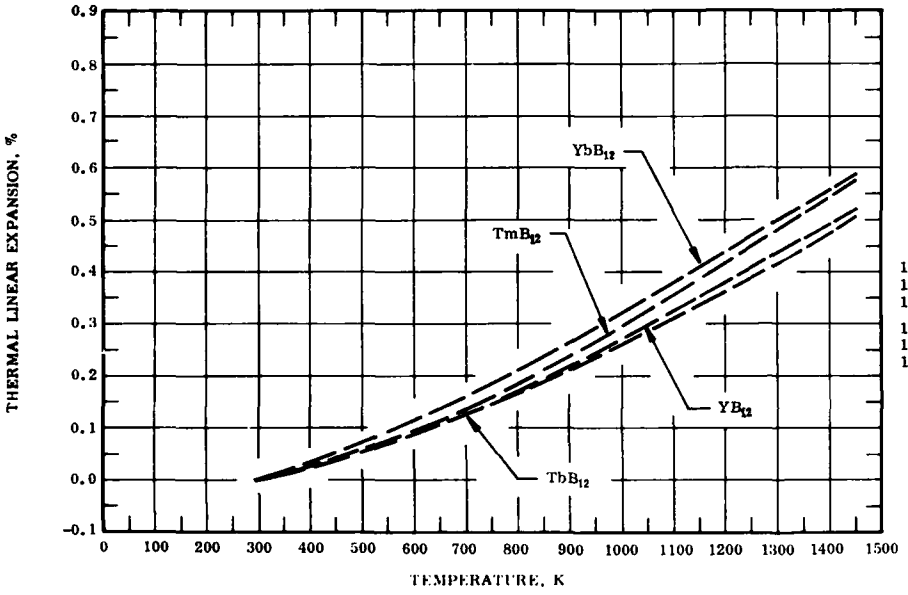
DATA TABLE 231. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIBORIDE + MOLYBDENUM DISILICIDE + ΣX_i $ZrB_2 + MoSi_2 + \Sigma X_i$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
700	0.262
922	0.412
1144	0.580
1366	0.751
1589	0.939
1811	1.147
2033	1.393
CURVE 2*	
293	0.000
473	0.113
673	0.247
873	0.380
1073	0.533
1273	0.677
CURVE 2 (cont.)*	
1473	0.847
1718	1.053
1928	1.293
2033	1.415
2138	1.635
2243	1.840
CURVE 3*	
293	0.000
473	0.100
673	0.233
873	0.390
1073	0.557
1273	0.713
1473	0.880
1718	1.183
CURVE 3 (cont.)*	
1928	1.417
2033	1.472
2138	1.604
2243	1.780
CURVE 4*	
293	0.000
1298	0.747
1513	0.970
1718	1.120
1938	1.367

* No figure given.

FIGURE AND TABLE NO. 232R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF MISCELLANEOUS DODECABORIDES



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	TbB_{12}		TmB_{12}		YB_{12}		YbB_{12}	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	1.5	0.000	1.7	0.000	1.6	0.000	2.2
400	0.021	2.4	0.023	2.6	0.021	2.3	0.028	3.0
500	0.049	3.1	0.052	3.3	0.047	2.9	0.061	3.7
600	0.083	3.7	0.088	3.9	0.080	3.5	0.101	4.3
700	0.123	4.3	0.130	4.5	0.117	4.0	0.146	4.8
800	0.168	4.7	0.178	5.0	0.160	4.5	0.196	5.2
900	0.216	5.0	0.230	5.4	0.207	5.0	0.250	5.6
1000	0.267	5.2	0.286	5.7	0.259	5.4	0.308	5.8
1100	0.320	5.4	0.344	6.0	0.314	5.8	0.368	6.0
1200	0.374	5.5	0.405	6.2	0.374	6.1	0.430	6.2
1300	0.427	5.6	0.468	6.4	0.437	6.4	0.492	6.3
1400	0.480	5.7	0.531	6.5	0.503	6.7	0.555	6.4
1450	0.505	5.7	0.563	6.6	0.537	6.9	0.586	6.5

REMARKS

The provisional values are based on the data for high purity samples. These values are considered accurate to within ±7% and are represented approximately by the following equations:

Terbium dodecaboride:

$$\Delta L/L_0 = -2.040 \times 10^{-3} - 1.508 \times 10^{-4}\, T + 5.872 \times 10^{-7}\, T^2 - 1.670 \times 10^{-10}\, T^3 \qquad (TbB_{12})$$

Thulium dodecaboride:

$$\Delta L/L_0 = -1.046 \times 10^{-2} - 1.097 \times 10^{-4}\, T + 5.337 \times 10^{-7}\, T^2 - 1.279 \times 10^{-10}\, T^3 \qquad (TmB_{12})$$

Yttrium dodecaboride:

$$\Delta L/L_0 = -1.875 \times 10^{-2} - 4.140 \times 10^{-5}\, T + 3.767 \times 10^{-7}\, T^2 - 5.786 \times 10^{-11}\, T^3 \qquad (YB_{12})$$

Ytterbium dodecaboride:

$$\Delta L/L_0 = -2.670 \times 10^{-2} - 4.732 \times 10^{-5}\, T + 5.101 \times 10^{-7}\, T^2 - 1.282 \times 10^{-10}\, T^3 \qquad (YbB_{12})$$

The tabulated values for the coefficient of thermal expansion are primarily based on the selected experimental data. These values are accurate to about ±10%.

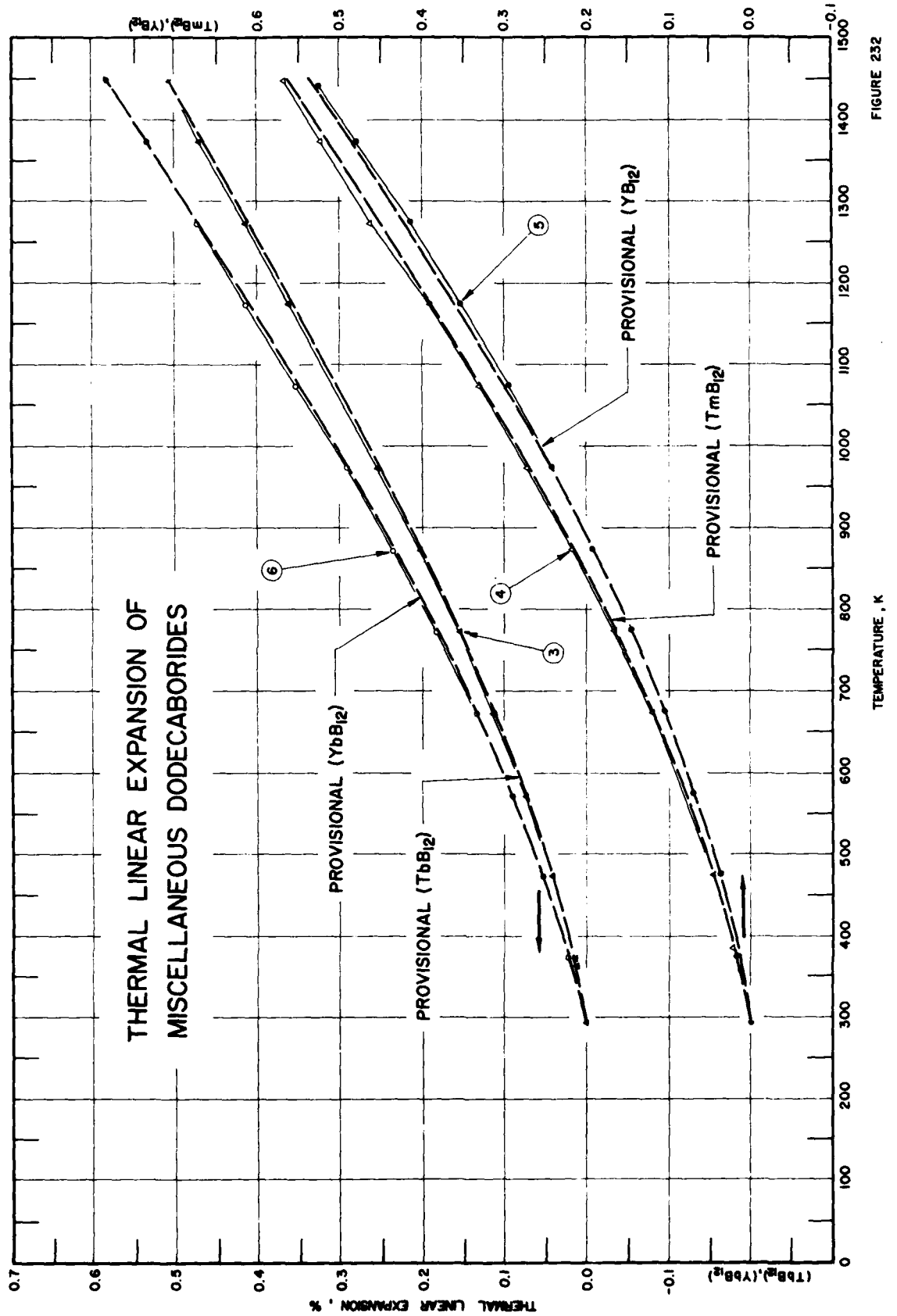

THERMAL LINEAR EXPANSION OF MISCELLANEOUS DODECABORIDES
PROVISIONAL (YbB_{12})
PROVISIONAL (TbB_{12})
PROVISIONAL (YB_{12})
PROVISIONAL (TmB_{12})
3
4
5
6
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
(TbB_{12}),(YbB_{12})
(TmB_{12}),(YB_{12})

FIGURE 232

SPECIFICATION TABLE 232. THERMAL LINEAR EXPANSION OF MISCELLANEOUS DODECABORIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	610	Paderno, Yu. B., Odinstov, V.V., Timofeeva, I.I., and Kleck Klochkov, L.A.	1970	X/L	293-1448	DyB_{12}	Dysprosium dodecaboride; cylindrical specimens; dimensions, 7 mm diameter x 10-12 mm long; made by vacuum reduction, then sintered at 7465 kg/cm²; x-ray method from 13-300 K and dilatometer from 300-1300 K; reported error 2%.
2*	610	Paderno, Yu. B., et al.	1970	X/L	293-1452	LuB_{12}	Lutetium dodecaboride; cylindrical specimen; dimensions, 7 mm diameter x 10-12 mm long; formed by vacuum reduction, then sintered at 7465 kg/cm²; x-ray method used from 13-300 K and dilatometer from 300-1300 K; reported error 2%.
3	610	Paderno, Yu. B., et al.	1970	X/L	293-1444	TbB_{12}	Terbium dodecaboride; cylindrical specimen; dimensions, 7 mm diameter x 10-12 mm long; prepared by vacuum reduction, then sintered at 7465 kg/cm²; x-ray method used from 13-300 K and dilatometer from 300-1300 K; reported error 2%.
4	610	Paderno, Yu. B., et al.	1970	X/L	293-1448	TmB_{12}	Thulium dodecaboride; cylindrical specimen; dimensions, 7 mm diameter x 10-12 mm long; formed by vacuum reduction, then sintered at 7465 kg/cm²; x-ray method used from 13-1300 K while the dilatometer was used from 300-1300 K; reported error 2%.
5	610	Paderno, Yu. B., et al.	1970	X/L	293-1450	YbB_{12}	Ytterbium dodecaboride; cylindrical specimen; dimensions 7 mm diameter x 10-12 mm long; formed by vacuum reduction, then sintered at 7465 kg/cm²; x-ray method used from 13-300 K and dilatometer from 300-1300 K; reported error 2%.
6	610	Paderno, Yu. B., et al.	1970	X/L	293-1441	YB_{12}	Yttrium dodecaboride; cylindrical specimen; dimensions, 7 mm diameter x 10-12 mm long; made by vacuum reduction, then sintered at 7465 kg/cm²; x-ray method used from 13-300 K and dilatometer from 300-1300 K; reported error 2%.
7*	610	Paderno, Yu. B., et al.	1970	X/L	293-1454	ZrB_{12}	Zirconium dodecaboride; dimensions, cylindrical 7.0 mm diameter x 10-12 mm long; specimen formed by vacuum reduction, then sintered at 7465 kg/cm²; x-ray method used from 13-300 K and dilatometer used from 300-1300 K.

* Not shown in figure.

DATA TABLE 232. THERMAL LINEAR EXPANSION OF MISCELLANEOUS DODECABORIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
293	0.000
364	0.014
373	0.016
473	0.042
573	0.075
673	0.113
773	0.158
873	0.207
973	0.260
1073	0.317
1173	0.377
1273	0.439
1373	0.504
1448	0.553

CURVE 2*

T	$\Delta L/L_0$
293	0.000
339	0.009
373	0.017
473	0.045
573	0.079
673	0.120
773	0.166
873	0.217
973	0.272
1073	0.331
1173	0.391
1273	0.454
1373	0.517
1452	0.568

CURVE 3

T	$\Delta L/L_0$
293	0.000
363	0.013
373	0.015
473	0.040
573	0.073
673	0.112
773	0.155
873	0.203
973	0.254
1073	0.307
1173	0.361

CURVE 3 (cont.)

T	$\Delta L/L_0$
1273	0.415
1373	0.470
1444	0.508

CURVE 4

T	$\Delta L/L_0$
293	0.000
383	0.019
473	0.044
573	0.079
673	0.120
773	0.167
873	0.218
973	0.272
1073	0.330
1173	0.390
1273	0.453
1373	0.517
1448	0.566

CURVE 5

T	$\Delta L/L_0$
293	0.000
373	0.021
473	0.052
573	0.090
673	0.133
773	0.183
873	0.236
973	0.293
1073	0.353
1173	0.414
1273	0.474
1373	0.535
1450	0.581

CURVE 6

T	$\Delta L/L_0$
293	0.000
357	0.011
373	0.014
473	0.039
573	0.071
673	0.107
773	0.148

CURVE 6 (cont.)

T	$\Delta L/L_0$
873	0.193
973	0.242
1073	0.296
1173	0.354
1273	0.416
1373	0.481
1441	0.528

CURVE 7

T	$\Delta L/L_0$
293	0.000*
363	0.013
373	0.015*
473	0.039
573	0.068*
673	0.102
773	0.141
873	0.185
973	0.234
1073	0.289
1173	0.348
1273	0.412
1373	0.480
1454	0.538

* Not shown in figure.

DATA TABLE 232. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS DODECABORIDES

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1*	
293	1.78
364	2.21
373	2.29
473	2.92
573	3.56
673	4.19
773	4.66
873	5.14
973	5.54
1073	5.84
1173	6.14
1273	6.35
1373	6.56
1448	6.30
CURVE 2*	
293	1.77
339	2.16
373	2.46
473	3.13
573	3.80
673	4.37
773	4.86
873	5.33
973	5.68
1073	5.96
1173	6.16
1273	6.31
1373	6.42
1452	6.47
CURVE 3	
293	1.54
363	2.10
373	2.18
473	2.94
573	3.58
673	4.13
773	4.60
873	4.95
973	5.23
1073	5.35
1173	5.42
1273	5.47
1373	5.47
1444	5.37
CURVE 4*	
293	1.80
383	2.45
473	3.12
573	3.85
673	4.42
773	4.88
873	5.31
973	5.62
1073	5.88
1173	6.13
1273	6.39
1373	6.54
1448	6.54
CURVE 5	
293	2.32
373	2.81
473	3.46
573	4.08
673	4.69
773	5.17
873	5.54
973	5.86
1073	6.07
1173	6.07
1273	6.04
1373	6.04
1450	6.04
CURVE 6*	
293	1.39
357	2.08
373	2.16
473	2.83
573	3.40
673	3.85
773	4.30
873	4.72
973	5.15
1073	5.62
1173	6.02
1273	6.38
1373	6.69
1441	6.94
CURVE 7	
293	1.64
363	2.10
373	2.14
473	2.65
573	3.15
673	3.62
773	4.16
873	4.67
973	5.20
1073	5.63
1173	6.20
1273	6.63
1373	7.01
1454	7.24

* Not shown in figure.

SPECIFICATION TABLE 233. THERMAL LINEAR EXPANSION OF MISCELLANEOUS BORIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	460	American Electro Metal Corp.	1955	X	293-612	CrB_2	Chromium diboride; expansion measured along a-axis; lattice parameter reported at 298 K as 1.4660 Å; 1.4659 Å at 293 K determined by graphical extrapolation.
2*	460	American Electro Metal Corp.	1955	X	298-609	CrB_2	Chromium diboride; expansion measured along c-axis; lattice parameter reported at 298 K as 1.5335 Å; 1.5335 Å at 293 K determined by graphical extrapolation.
3*	471	Meerson, G.A., Samsonov, G.V., Kotel'nikov, R.B., Voinova, M.S., Euteeva, I.P., and Krasnenkova, S.D.	1958	L	293,973	CrB_2	Chromium diboride; specimen 8 mm in diameter, 15-20 mm in height; prepared by sintering mixtures of boride powders by the method of hot molding in graphite die.
4*	607	Bentz, G., Provost, G., and Urban, C.	1968	X	273-1873	CrB	Chromium boride; 74.02 Cr, 25.31 Br, impurities <0.61; specimen formed by plasma spray; crystal shape hexagonal; crystal reorientation from 1173-1673 K; heating phase; zero-point correction is -0.2%.
5*	607	Bentz, G., et al.	1968	X	2073-273	CrB	Chromium boride; the above specimen; expansion measured with decreasing temperature; zero-point correction is 1.57%.
6*	608	Samsonov, G.V., Grebenkina, V.G., Vusov, Yu.P., Vlasov, L.G., and Perevezentsev, A.V.	1971	X	400, 1400	CrB_2	Chromium diboride; sintered powder; data taken from smooth curve which authors generated from their two experimental points.
7*	726	Samsonov, G.V., Bolgor, A.S., Kavenskaya, B.A., Guseva, E.A., Serebrykavo, T.I., Klockhov, L.A., Turchanin, A.G., and Fresenko, V.V.	1973	X	300, 1300	CrB_2	Chromium diboride; no details given.
8*	726	Samsonov, G.V., et al.	1973	X	1300, 2000	CrB_2	Chromium diboride; no details given.
9*	609	Iga, A.	1970		293-673	Co_2B	Cobalt boride; linear expansion of lattice parameter measured along a-axis; 5.017 Å reported at 293 K.
10*	609	Iga, A.	1970		293-673	Co_2B	Cobalt boride; the above specimen; lattice parameter measured along c-axis; 4.219 Å reported at 293 K.
11*	609	Iga, A.	1970		293-873	Fe_2B	Iron boride; a-axis lattice parameter reported at 293 K as 5.113 Å.
12*	609	Iga, A.	1970		293-873	Fe_2B	Iron boride; the above specimen; c-axis lattice parameter reported at 293 K as 4.232 Å.
13*	614	Kunitskii, Yu.A. and Marek, E.V.	1969	L	293-1273	Fe_2B	Iron boride; 90.8 Fe, 9.0 B, <0.1 Cr, <1 Sc, <0.05 Mn, and <0.05 Ni; dimensions of cylindrical specimen 8.0 mm diameter, 16.0 mm length; prepared by sintering pressed blanks in argon atmosphere at temperature 1473 K, annealed in vacuum.
14*	615	Kostetskii, I.I., L'vov, S.N., and Kunitskii, Yu.A.	1970	L	288-1212	Fe_2B	Iron boride; impurities of Si, Cr, Mn, Ti all less than 0.05; synthesizing, hot pressing and anneal at an atmosphere of 10^{-4} mm Hg.
15*	460	American Electro Metal Corp.	1955	X	300-884	MoB_2	Molybdenum diboride; expansion measured along a-axis; lattice parameter reported at 300 K as 1.5181 Å; 1.5180 Å at 293 K determined by graphical extrapolation.
16*	460	American Electro Metal Corp.	1955	X	296-886	MoB_2	Molybdenum diboride; expansion measured along c-axis; lattice parameter reported at 290 K as 1.5276 Å; 1.5276 Å at 293 K determined by graphical extrapolation.

* No figure given.

SPECIFICATION TABLE 233. THERMAL LINEAR EXPANSION OF MISCELLANEOUS BORIDES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
17*	460	American Electro Metal Corp.	1955	X	293-882	MoB_2	Molybdenum diboride; no details given.
18*	460	American Electro Metal Corp.	1955	X	293-887	MoB_2	Molybdenum diboride; no details given.
19*	617	Samsonov, G.V., Zhuravlev, N.N., Paderno, Yu.B., and Melik-Adamyan, V.R.	1960		293,1073	SmB_6	Samarium hexaboride; specimen prepared by the reaction $SM_2O_3 + 15\ B \rightarrow 2\ SmB_6 + 3\ BO$, while heating at 1923 K under vacuum.
20*	1030	Zhuravlov, N.N. and Stepanova, A.A.	1964	X	287-873	ScB_2	Scandium boride; powder sample prepared and lent by the IPM Cermet Institute of the Ukrainian Academy of Sciences; x-ray method; copper radiation; data calculated from lattice parameter; measured in c-axis direction.
21*	1030	Zhuravlov, N.N. and Stepanova, A.A.	1964	X	287-873	ScB_2	Scandium boride; similar to the above specimen except measured in a-axis direction.
22*	618	Feigelson, R.S.	1962		293-1273	SiB_6	Silicon hexaboride; 1.0 Cu, 0.1-1.0 each Fe, Ni, 0.1 each Al, Cr, Mn, Ti, 0.01-0.1 each Mg, Zr, 0.4 O, 0.0153 N, 0.0647 H; specimen 0.141 in. in diameter, 0.675 in. in length; specimen prepared by prepressing to 100,000 psi with 4% carbowax, and hot pressing to 1773 K for 2 hr at 6000 psi in an unlined graphite die, and then machined with diamond tools; bulk density 2.32 g cm^{-3}; measured in argon with a heating rate of 8 K per minute.
23*	618	Feigelson, R.S.	1962		293-1273	SiB_4	Silicon tetraboride; 1.0 Cu, 0.1-1.0 each Fe, Zr, 0.1 each Al, Cr, Mn, Ni, 0.01-0.1 each Mg, Ti, 0.43 O, 0.072 H, 0.0141 N; specimen 0.142 in. in diameter, 0.8810 in. in length; sample prepared by prepressing to 100,000 psi with 4% carbowax, and hot pressing at 1623 K for 4 hr at 6000 psi in an unlined graphite die, and then machined with diamond tools; bulk density 2.08 g cm^{-3}; measured in argon with a heating rate of 8 K per minute.
24*	318	Neel, D.S., Pears, C.D., and Oglesby, S., Jr.	1962		294-2661	TaB	Tantalum boride; specimen may contain considerable diboride; initial length 3.1530 in.; final length 3.0940 in.; General Electric Co.; specimen partially melted on post inspection; Run SRI-E25; measured in helium atmosphere; reported error 2%.
25*	318	Neel, D.S., et al.	1962		2661,2099	TaB	Tantalum boride; expansion given in decreasing temperatures to 2099.8 K; reported error 2%.
26*	318	Neel, D.S., et al.	1962		2099-2811	TaB	Tantalum boride; expansion given in increasing temperatures to 2810.8 K in second thermal cycle; reported error 2%.
27*	318	Neel, D.S., et al.	1962		2816,294	TaB	Tantalum boride; expansion given in decreasing temperatures to 294.2 K; reported error 2%.
28*	172	Aronson, S., Cisney, E., and Gingerich, K.A.	1967	X	1174-1951	ThB_6	Thorium hexaboride; sample prepared by heating mixtures of thorium and boron powders, pressed into the shape at cylinders, in vacuo at either 1400-1450 C for 2-3 hr or at 1000 C for 300-500 hr; reacts with additional boron to form ThB_6; CuKα radiation; (321), (410), (411), and (421) lines used; melting point 2195 C.
29*	63	Pears, C.D. and Oglesby, S.	1962		294-2513	ThB_4	Thorium tetraboride; initial length 2.275 in., final length 2.265 in.; Carborundum Co.; hot pressed; Run No. E20; density in g cm^{-3} at 298 K; 7.78 by ASTM method B311-58, 7.82 by wax-coating specimen, and 8.17 by immersion in xylene; measured in helium atmosphere; reported error 5%.
30*	63	Pears, C.D. and Oglesby, S.	1962		2513,294	ThB_4	Thorium tetraboride; similar to the above specimen except expansion given in decreasing temperatures; reported error 5%.

* No figure given.

SPECIFICATION TABLE 233. THERMAL LINEAR EXPANSION OF MISCELLANEOUS BORIDES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
31*	63	Pears, C.D. and Oglesby, S.	1963	L	293-2672	WB	Tungsten boride; 95.3 W, 4.7 B; elements found by semi-quantitative emission spectrography before exposure 0.2 Si, 0.2 V, 0.2 Fe, 0.2 Nb, 0.1 Zr, after exposure 94.8 W, 5.2 B, and 0.09 C; initial length 2.332 in.; Carborundum Co.; hot pressed; specimen melted at 2672 K; Run No. E3; density in g cm^{-3} at 298 K before exposure 15.2 by ASTM method B311-58, 15.0 by wax-coating specimen, 15.3 by immersion in xylene, after exposure 14.7 by ASTM method, 14.7 by wax-coating specimen, and 14.8 by immersion in xylene; measured in helium atmosphere; reported error 5%.
32*	63	Pears, C.D. and Oglesby, S.	1963	L	293-2665	WB	Tungsten boride; the above specimen, data reported from graph.
33*	900	Beckman, G. and Kiessling, R.	1956	X	298-478	UB_2	Uranium boride; expansion measured in a-axis direction.
34*	900	Beckman, G. and Kiessling, R.	1956	X	298-478	UB_2	Uranium boride; the above specimen; expansion measured in c-axis direction.
35*	900	Beckman, G. and Kiessling, R.	1956	X	298-478	UB_2	Uranium boride; the above specimen; expansion measured in direction of U-B bond.

* No figure given.

DATA TABLE 233. THERMAL LINEAR EXPANSION OF MISCELLANEOUS BORIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
300	0.007
383	0.034
491	0.101
612	0.195
CURVE 2*	
293	0.000
298	0.000
380	0.046
488	0.117
609	0.222
CURVE 3*	
293	0.00
973	0.67
CURVE 4*	
273	-0.02
293	0.00
373	0.09
473	0.15
573	0.26
673	0.36
773	0.44
873	0.53
973	0.61
1073	0.70
1173	0.80
1273	0.89
1323	0.97
1373	1.05
1423	1.16
1473	1.26
1523	1.37
1573	1.49
1623	1.60
1673	1.66
1723	1.72
1773	1.76
1823	1.78
1873	1.78

T	$\Delta L/L_0$
CURVE 5*	
2073	1.57
2023	1.48
1973	1.38
1923	1.30
1873	1.22
1823	1.18
1773	1.13
1723	1.11
1673	1.08
1623	1.06
1573	1.03
1523	1.00
1473	0.97
1423	0.95
1373	0.90
1323	0.86
1273	0.82
1173	0.73
1073	0.66
973	0.57
873	0.48
773	0.40
673	0.32
573	0.25
473	0.16
373	0.08
293	0.00
273	-0.02
CURVE 6*	
400	0.099
1400	1.127
CURVE 7*	
300	0.007
1300	1.057
CURVE 8*	
1300	1.188
2000	2.014

T	$\Delta L/L_0$
CURVE 9*	
293	0.000
373	0.080
473	0.239
573	0.359
673	0.498
CURVE 10*	
293	0.000
373	0.071
473	0.166
573	0.308
673	0.450
CURVE 11*	
293	0.000
373	0.059
473	0.137
573	0.274
673	0.430
773	0.548
873	0.724
CURVE 12*	
293	0.000
373	0.047
473	0.118
573	0.212
673	0.329
773	0.423
873	0.564
CURVE 13*	
293	0.000
376	0.067
468	0.142
535	0.197
613	0.261
690	0.325
775	0.396
860	0.468
956	0.552
1026	0.618

T	$\Delta L/L_0$
CURVE 13*	
1055	0.649
1080	0.676
1103	0.703
1137	0.742
1169	0.777
1192	0.800
1222	0.826
1239	0.838
1273	0.857
CURVE 14*	
288	-0.004
293	0.000
375	0.065
470	0.142
541	0.199
601	0.248
684	0.314
769	0.382
854	0.450
957	0.535
1020	0.593
1049	0.623
1104	0.684
1136	0.720
1165	0.751
1189	0.775
1212	0.795
CURVE 15*	
300	0.00659
378	0.0988
491	0.165
610	0.250
745	0.316
884	0.408
CURVE 16*	
296	0.000
380	0.0589
489	0.216
745	0.426
886	0.596

T	$\Delta L/L_0$
CURVE 17*	
293	0.000
300	-0.013
377	0.072
489	0.132
610	0.217
744	0.283
882	0.382
CURVE 18*	
293	0.000
296	0.007
381	0.065
489	0.216
745	0.425
887	0.589
CURVE 19*	
293	0.00
1073	0.005
CURVE 20*	
287	-0.006
293	0.000
472	0.120
569	0.225
673	0.319
773	0.370
873	0.430
CURVE 21*	
287	-0.006
293	0.000
470	0.124
673	0.261
774	0.331
873	0.398
CURVE 22*	
293	0.000
473	0.095
573	0.121

T	$\Delta L/L_0$
CURVE 22 (cont.)*	
673	0.170
773	0.223
873	0.275
973	0.320
1073	0.381
1273	0.517
CURVE 23*	
293	0.000
473	0.095
573	0.138
673	0.196
773	0.255
873	0.295
973	0.372
1073	0.438
1173	0.500
1273	0.620
CURVE 24*	
294	0.00
866	0.22
994	0.30
1072	0.39
1213	0.52
1394	0.62
1544	0.72
1649	0.80
1755	0.86
1888	0.92
2005	0.99
2116	1.07
2255	1.14
2310	1.16
2394	1.22
2600	1.32
2661	1.23
CURVE 25*	
2661	-0.91
2099	-1.38

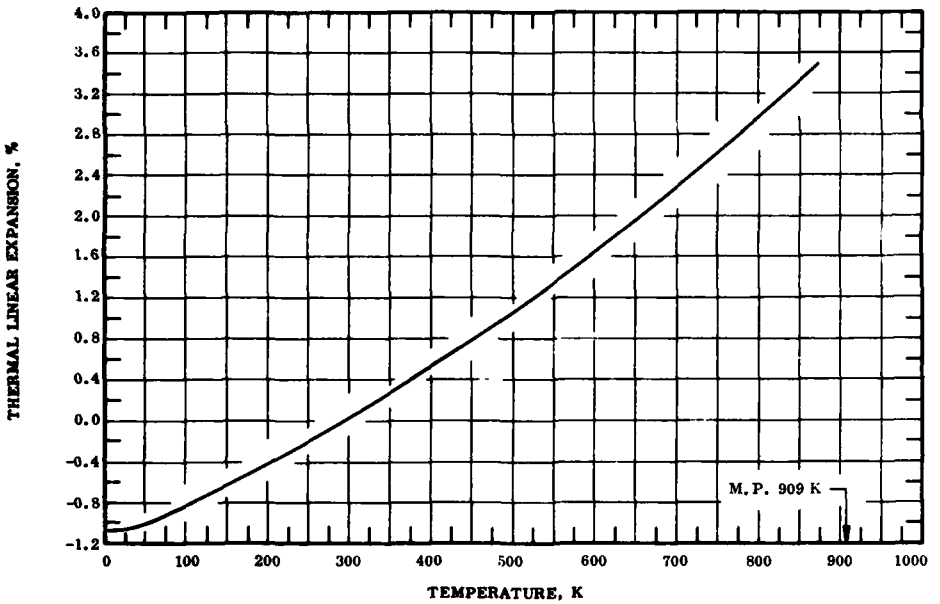
* No figure given.

DATA TABLE 233. THERMAL LINEAR EXPANSION OF MISCELLANEOUS BORIDES (continued)

T	$\Delta L/L_0$
CURVE 26*	
2099	-1.38
2255	-1.27
2316	-1.24
2422	-1.16
2427	-1.15
2444	-1.13
2463	-1.12
2544	-1.06
2588	-1.04
2616	-1.01
2700	-0.95
2727	-0.92
2811	-0.84
CURVE 27*	
2816	-0.84
294	-2.31
CURVE 28*	
1174	0.725
1282	0.858
1379	0.951
1482	1.098
1488	1.076
1640	1.271
1690	1.318
1797	1.416
1902	1.558
1951	1.616
CURVE 29*	
294	0.00
376	0.02
533	0.08
810	0.30
1106	0.52
1115	0.52
1333	0.71
1619	0.97
1849	1.21
1910	1.26
2118	1.47
2188	1.51
2513	1.50
CURVE 30*	
2513	1.50
294	-0.64
CURVE 31*	
293	0.00
534	0.10
870	0.32
1116	0.47
1372	0.65
1599	0.81
1894	1.04
2199	1.28
2435	1.52
2672	1.74
CURVE 32*	
293	0.000
533	0.107
875	0.323
1117	0.471
1378	0.657
1600	0.819
1891	1.046
2193	1.285
2424	1.522
2665	1.736
CURVE 33*	
298	0.0045
478	0.167
CURVE 34*	
298	0.004
478	0.148
CURVE 35*	
298	0.003
478	0.111

* No figure given.

FIGURE AND TABLE NO. 234R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF CESIUM BROMIDE CsBr



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
2	-1.077	0.01
5	-1.077	0.12
10	-1.076	1.5
15	-1.075	5.2
20	-1.071	10.0
25	-1.065	15.0
50	-1.004	31.6
75	-0.920	35.8
100	-0.827	38.2
150	-0.629	41.0
200	-0.418	43.2
250	-0.197	45.2
293	0.000	46.8
350	0.274	49.4
400	0.526	51.5
500	1.063	55.9
600	1.645	60.5
700	2.274	65.2
800	2.950	70.0
875	3.489	73.8

REMARKS

The recommended values are based on the data for high-purity samples. These values are considered accurate to within ±3% at temperatures below 600 K and ±5% above 600 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -1.197 + 3.501 \times 10^{-3} T + 1.929 \times 10^{-6} T^2 + 2.180 \times 10^{-10} T^3 \quad (100\text{-}875\ K)$$

The tabulated values for the coefficient of thermal expansion are based on the experimental data and are considered accurate to about ±7%.

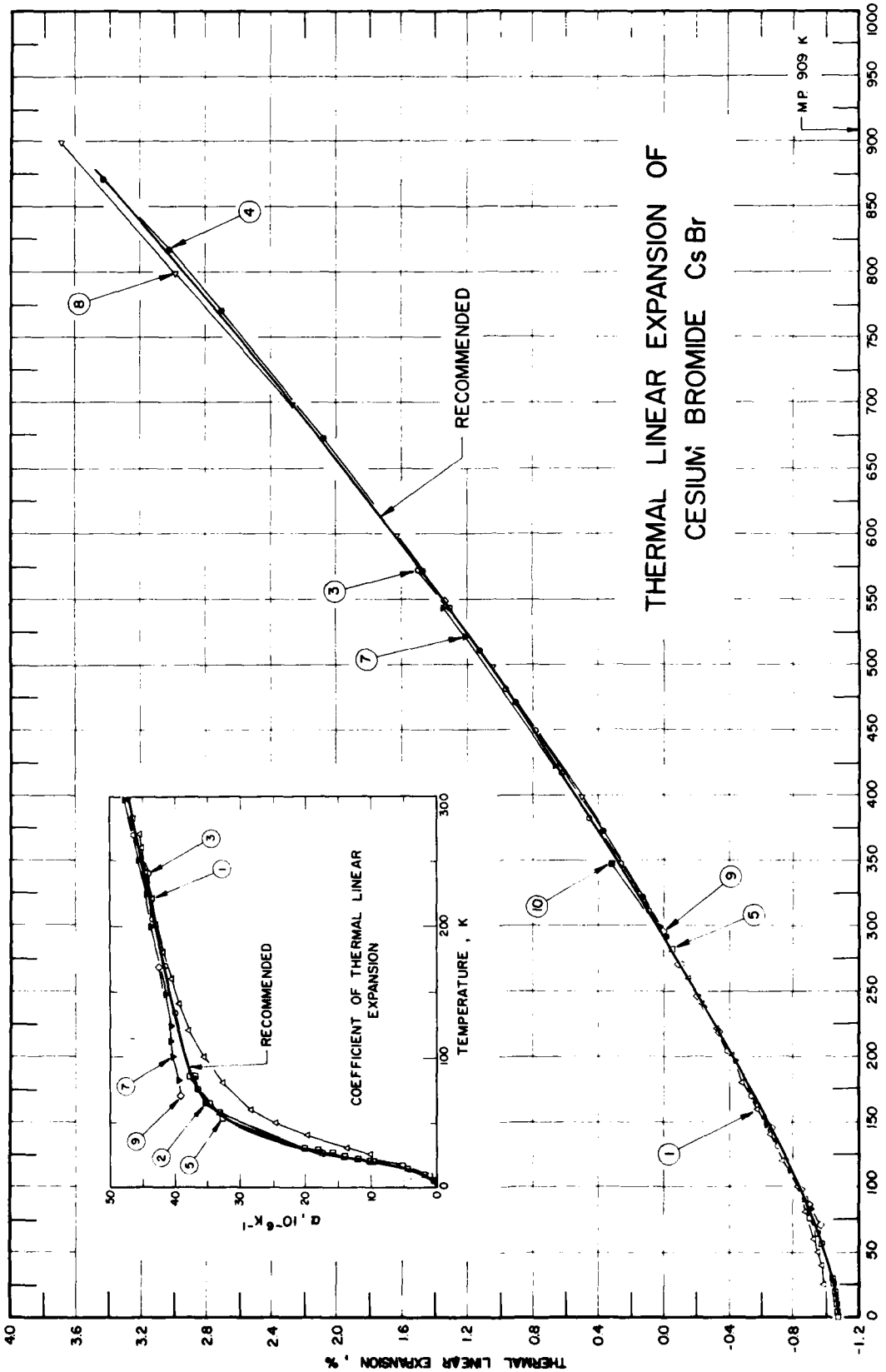

THERMAL LINEAR EXPANSION OF
CESIUM BROMIDE Cs Br
RECOMMENDED
MP 909 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹

FIGURE 234

SPECIFICATION TABLE 234. THERMAL LINEAR EXPANSION OF CESIUM MONOBROMIDE CsBr

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	619	Bailey, A.C. and Yates, B.	1967	I	25-270		Specimen hollow cylinder 99.5+ pure, from Hilger and Watts, Ltd., O.D. 2.7 cm, I.D. 1.8 cm, 1.0 cm high.
2*	479	White, G.K.	1965	C	4-85		Optical quality specimen from Isomet Corp. of New Jersey; specimen cylinder 2 cm diameter, ~5 cm long; data smoothed by author; this curve is here reported using 4.0 K as the reference temperature at which $\Delta L/L_0 = 0$.
3	620	Krishnan, R.S. and Srinivasan, R.	1956	I	134-574		Single crystal of cesium bromide was synthetic origin and grown from melt, the specimen, procured from Messrs. Hilger and Watts Ltd.; three pyramids of 0.367 cm height, prepared from crystal and used as the spacers in the interferometer; body-centered-cubic ionic structure.
4	621, 622	Pathak, P.D. and Vasavada, N.G.	1970	X	293-872		Powder specimen.
5	623	White, G.K. and Collins, J.G.	1973	E	2-283		Cylindrical specimens of 20 mm diameter; 50.8 mm long; specimen of optical crystal quality from Isomet Corp. of New Jersey.
6*	623	White, G.K. and Collins, J.G.	1973	E	2-14		The above specimen; results obtained later in the year; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
7	624	Rapp, J.	1969	L	83-573		Dimensions: 5 mm x 5 mm x 25 mm; specimen obtained by Semi-Elements Inc. of Pennsylvania as single crystals; (111) crystal face was perpendicular to major axis of specimen.
8	625	Srivastava, K.K. and Merchant, H.D.	1972	X	293-900		No details given.
9	626	Rapp, J.E. and Merchant, H.D.	1972	L	69-574		Crystal orientation was <1, 1, 1>; dimensions were 5 x 5 x 25 mm; smoothed data.
10	632	Bridgman, P.W.	1932		303, 348		Specimen pressed into a 9.525 mm diameter by 9.525 mm to 12.7 mm long cylinder; used lever piezometer method.

* Not shown in figure.

DATA TABLE 234. THERMAL LINEAR EXPANSION OF CESIUM MONOBROMIDE CsBr

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1‡

T	$\Delta L/L_0$
25	-0.989
30	-0.984*
40	-0.970
50	-0.951
60	-0.926
80	-0.869
100	-0.804
120	-0.733
140	-0.657
160	-0.578
180	-0.496
200	-0.412
220	-0.326
240	-0.239
260	-0.150
270	-0.104*

CURVE 2*, †

T	$\Delta L/L_0$
4	0.00000000
5	0.00000935
6	0.0000271
7	0.0000606
8	0.000117
10	0.000337
12	0.000757
14	0.00145
16	0.00249
18	0.00391
20	0.00572
22	0.00792
24	0.0105
26	0.0135
28	0.0169
30	0.0207
37.5	0.0934
65	0.119
75	0.154
85	0.192

CURVE 3‡

T	$\Delta L/L_0$
133.9	-0.694
170.3	-0.545
205.3	-0.397
239.3	-0.248
271.9	-0.100
313.2	0.094
349.4	0.271
384.1	0.448
417.7	0.624
450.5	0.799
482.4	0.973
513.6	1.149
544.0	1.323
574.0	1.497

CURVE 4‡

T	$\Delta L/L_0$
293	0.000
323	0.142
373	0.386
473	0.905
573	1.465
674	2.072
772	2.708
818	3.030
872	3.440

CURVE 5‡

T	$\Delta L/L_0$
1.846	-1.068*
2.422	-1.068*
3.045	-1.068*
3.586	-1.068*
4.028	-1.068*
4.404	-1.068*
4.809	-1.068*
5.235	-1.068
5.612	-1.067*
5.952	-1.067*
6.337	-1.067*
6.775	-1.067*
7.215	-1.067*
7.766	-1.067*
8.401	-1.067*
9.085	-1.067*
9.800	-1.067*
10.618	-1.067
11.597	-1.067*
12.743	-1.067*
13.938	-1.066*
15.127	-1.066
16.483	-1.065*
18.041	-1.064*
19.027	-1.063*
21.234	-1.060
23.004	-1.058*
24.825	-1.056*
26.478	-1.053
27.824	-1.051*
29.166	-1.048
57	-0.977
65	-0.950
75	-0.914
85	-0.877
283	-0.042

CURVE 6*, †, ‡

T	$\Delta L/L_0$
2.474	0.000
3.128	0.014
3.650	0.034
4.052	0.057
4.410	0.084
4.798	0.123
5.211	0.177
5.581	0.240
5.936	0.316
6.329	0.423
6.739	0.563
7.191	0.758
7.731	1.060
8.369	1.529
8.982	2.116
9.494	2.724
10.028	3.485
10.689	4.635
11.612	6.678
12.758	10.020
13.931	14.487

CURVE 7‡

T	$\Delta L/L_0$
83	-0.907
98	-0.847*
113	-0.787
123	-0.746*
148	-0.643
173	-0.538*
198	-0.430
223	-0.321*
248	-0.208*
273	-0.094*
298	0.023
323	0.143*
373	0.391*
423	0.650
473	0.920*
523	1.203
548	1.350
573	1.500*

CURVE 8‡

T	$\Delta L/L_0$
293	0.000*
300	0.032*
400	0.520
500	1.058
600	1.644
700	2.279
800	2.961
900	3.683

CURVE 9‡

T	$\Delta L/L_0$
69	-0.962
81	-0.914
96	-0.855
145	-0.655
168	-0.558*
219	-0.337
246	-0.216
271	-0.102
293	0.000*
296	0.014
324	0.148*
374	0.395*
425	0.658*
473	0.918*
523	1.201*
550	1.359
574	1.502*

CURVE 10

T	$\Delta L/L_0$
303	0.059*
348	0.328

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 234. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CESIUM MONOBROMIDE CsBr

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
25	10.0
30	13.6
40	19.6
50	24.5
60	28.3
80	32.8
100	35.6
120	37.8
140	39.5
160	40.9
180	42.0
200	43.0
220	43.8
240	44.5
260	45.2
270	45.6
CURVE 2‡	
4	0.62
5	1.25*
6	2.3*
7	4.4*
8	7.0*
10	1.5
12	2.7*
14	4.3
16	6.1*
18	8.1*
20	10.0
22	12.0
24	14.0
26	16.0
28	18.1
30	20.0
57.5	32.9
65	35.2
75	36.7
85	37.9
CURVE 3‡	
133.9	40.0
170.3	41.7
205.3	43.3
239.3	44.0
CURVE 3 (cont.)‡	
271.9	46.6
313.2	47.7*
349.4	50.1*
384.1	51.7*
417.7	52.9*
450.5	54.1*
482.4	55.2*
513.6	57.0*
544.0	57.7*
574.0	58.7*
CURVE 4*,‡	
293	46.8
323	47.7
373	49.8
473	54.0
573	58.1
674	62.1
772	67.6
818	72.7
872	79.2
CURVE 5‡	
1.846	0.0053*
2.422	0.0127*
3.045	0.0271*
3.586	0.0442*
4.028	0.0635*
4.404	0.0846*
4.809	0.1138*
5.235	0.1515*
5.612	0.1930*
5.952	0.2320*
6.337	0.3050*
6.775	0.3850*
7.215	0.4850*
7.766	0.6390*
8.401	0.8330*
9.085	1.1040
9.800	1.4340*
10.618	1.8630*
11.597	2.4660*
12.743	3.3040*
13.938	4.2670*
CURVE 5 (cont.)‡	
15.127	5.3120
16.483	6.6050*
18.041	8.1150*
19.027	9.7330
21.234	11.35*
23.004	13.17*
24.825	14.96*
26.478	16.49*
27.824	17.71*
29.166	18.85*
57	32.70*
65	34.80
75	36.50*
85	37.80
283	46.50
CURVE 6*,‡	
2.474	0.0146
3.128	0.0288
3.650	0.0483
4.052	0.0646
4.410	0.0857
4.798	0.1143
5.211	0.1499
5.581	0.1902
5.936	0.2395
6.329	0.3040
6.739	0.3790
7.191	0.4840
7.731	0.6320
8.369	0.8400
8.982	1.0730
9.494	1.3040
10.028	1.5450
10.689	1.9340
11.612	2.4940
12.758	3.3390
13.931	4.2770
CURVE 7‡	
83	39.58
98	40.04
113	40.51
123	40.83
CURVE 7 (cont.)‡	
148	41.67
173	42.54*
198	43.45
223	44.38
248	45.34
273	46.35
298	47.37
323	48.43*
373	50.62*
423	52.93*
473	55.34*
523	57.89*
548	59.25*
573	60.54*
CURVE 8*,‡	
293	45.50
300	46.10
400	51.50
500	56.10
600	61.00
700	66.00
800	70.40
900	74.10
CURVE 9‡	
69	39.3
81	39.5*
96	40.0*
145	41.5*
168	42.4
219	44.3*
246	45.3*
271	46.0*
293	47.0*
296	47.1*
324	48.3*
374	50.5*
425	52.9*
473	55.4*
523	57.8*
550	59.1*
574	60.3*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

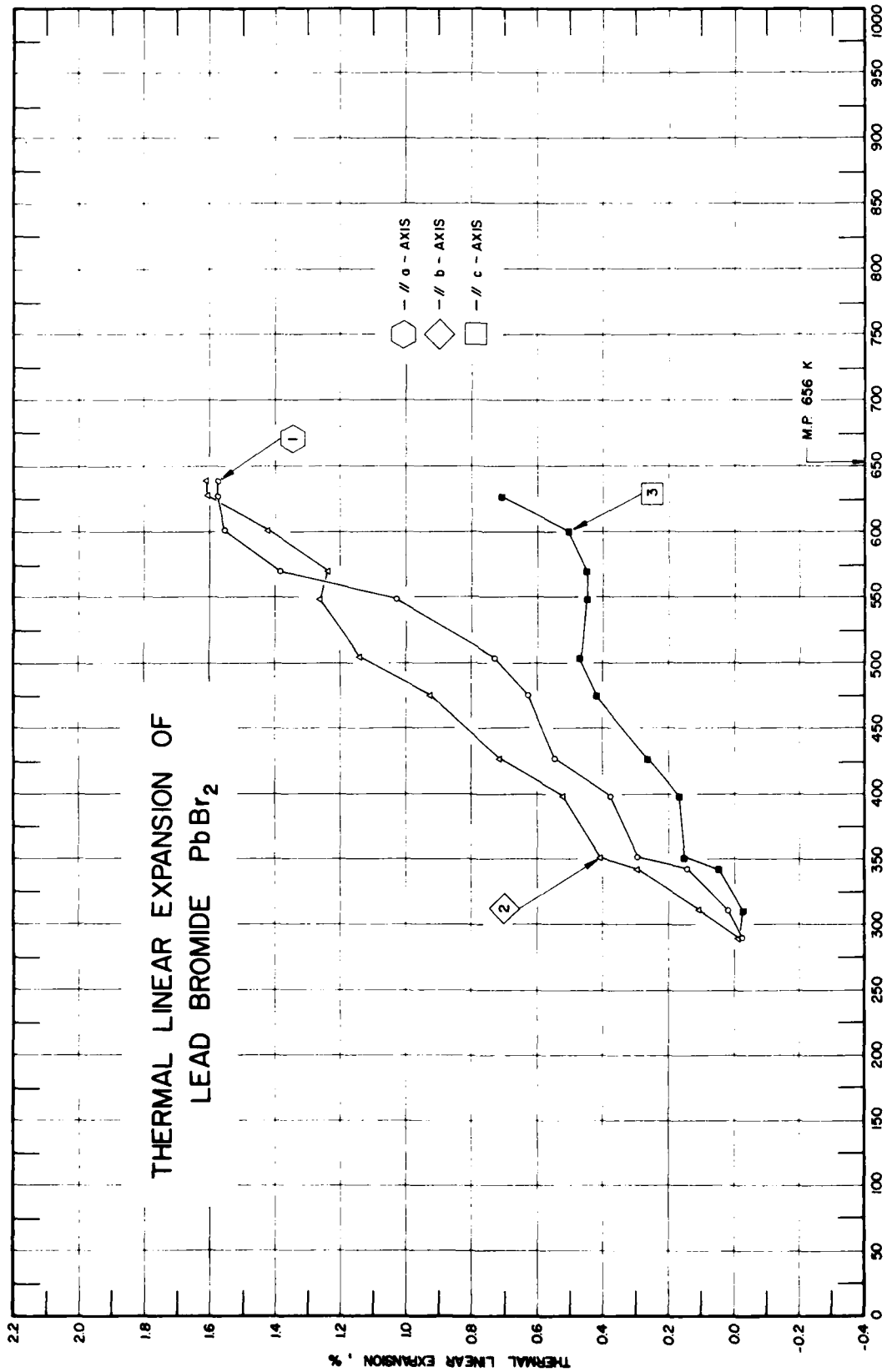

THERMAL LINEAR EXPANSION OF
LEAD BROMIDE $PbBr_2$
// a - AXIS
// b - AXIS
// c - AXIS
M.P. 656 K
1
2
3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 235

SPECIFICATION TABLE 235. THERMAL LINEAR EXPANSION OF LEAD BROMIDE $PbBr_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	295	Hsu, Y. T.	1967	X	290-638		Reagent quality powdered orthorhombic crystals in 0.3 mm diameter capillary; lattice expansion measured along a-axis; $\Delta L/L_0$ calculated from average of reported lattice parameter; lattice parameter reported at 290 K is 4.746 Å; 4.747 Å at 293 K determined by graphical interpolation.
2	295	Hsu, Y. T.	1967	X	290-638		The above specimen; lattice expansion measured along b-axis; $\Delta L/L_0$ calculated from average of reported lattice parameter; lattice parameter reported at 290 K is 8.064 Å; 8.065 Å at 293 K determined by graphical interpolation.
3	295	Hsu, Y. T.	1967	X	290-627		The above specimen; lattice expansion measured along c-axis; $\Delta L/L_0$ calculated from average of reported lattice parameter; lattice parameter reported at 290 K is 9.541 Å; 9.542 Å at 293 K determined by graphical interpolation.

DATA TABLE 235. THERMAL LINEAR EXPANSION OF LEAD BROMIDE $PbBr_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3	
290	-0.021	290	-0.012	290	-0.010*
311	0.021	311	0.112	311	-0.021
342	0.147	342	0.298	342	0.052
351	0.295	351	0.409	351	0.157
398	0.379	398	0.533	398	0.168
427	0.548	427	0.719	427	0.262
475	0.632	475	0.930	475	0.419
503	0.737	503	1.141	503	0.472
548	1.032	548	1.265	548	0.451
570	1.390*	570	1.240	570	0.451
601	1.559*	601	1.426	601	0.503
627	1.580*	627	1.612*	627	0.713
638	1.580*	638	1.612*		

* Not shown in figure.

SPECIFICATION TABLE 236. THERMAL LINEAR EXPANSION OF MANGANESE BROMIDE TETRAHYDRATE $MnBr_2 \cdot 4H_2O$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	627	Philp, J.W., Gonano, R., and Adams, E.D.	1969	E	0.6–4.2		Sample 0.6 cm cube cut with wet wire from crystal which grown by evaporation from saturated solution, cut axes parallel to a, b, c' axes, had a number of visible flaws; expansion measured in a-axis direction; this curve is here reported using 0.6 K as reference temperature at which $\Delta L/L_0 = 0$.
2*	627	Philp, J.W., et al.	1969	E	0.6–4.2		Similar to the above specimen; cube cut from different crystal; expansion measured in b-axis direction; this curve is here reported using 0.6 K as reference temperature at which $\Delta L/L_0 = 0$.
3*	627	Philp, J.W., et al.	1969	E	0.6–4.2		Similar to the above specimen; cube cut from different crystal; expansion measured in c'-axis direction; this curve is here reported using 0.5 K as reference temperature at which $\Delta L/L_0 = 0$.

* No figure given.

DATA TABLE 236. THERMAL LINEAR EXPANSION OF MANGANESE BROMIDE TETRAHYDRATE $MnBr_2 \cdot 4H_2O$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 2*,‡		CURVE 2 (cont.)*,‡		CURVE 3*,‡		CURVE 3 (cont.)*,‡	
0.6	0.000×10^{-4}	2.6	-6.112×10^{-4}	0.6	0.000×10^{-4}	2.6	-1.616×10^{-4}	0.5	0.000×10^{-4}	2.6	-5.033×10^{-4}
0.7	-0.041	2.7	-6.172	0.7	-0.011	2.7	-1.662	0.6	-0.021	2.7	-5.118
0.8	-0.104	2.8	-6.223	0.8	-0.029	2.8	-1.705	0.7	-0.056	2.8	-5.194
0.9	-0.192	2.9	-6.267	0.9	-0.055	2.9	-1.745	0.8	-0.110	2.9	-5.264
1.0	-0.309	3.0	-6.306	1.0	-0.089	3.0	-1.783	0.9	-0.187	3.0	-5.328
1.1	-0.461	3.1	-6.341	1.1	-0.133	3.1	-1.819	1.0	-0.288	3.1	-5.387
1.2	-0.653	3.2	-6.372	1.2	-0.187	3.2	-1.853	1.1	-0.418	3.2	-5.442
1.3	-0.890	3.3	-6.400	1.3	-0.251	3.3	-1.886	1.2	-0.580	3.3	-5.493
1.4	-1.179	3.4	-6.425	1.4	-0.327	3.4	-1.917	1.3	-0.777	3.4	-5.541
1.5	-1.528	3.5	-6.448	1.5	-0.415	3.5	-1.947	1.4	-1.014	3.5	-5.585
1.6	-1.945	3.6	-6.469	1.6	-0.518	3.6	-1.976	1.5	-1.295	3.6	-5.627
1.7	-2.440	3.7	-6.487	1.7	-0.636	3.7	-2.005	1.6	-1.627	3.7	-5.665
1.8	-3.028	3.8	-6.505	1.8	-0.774	3.8	-2.033	1.7	-2.018	3.8	-5.701
1.9	-3.741	3.9	-6.521	1.9	-0.934	3.9	-2.060	1.8	-2.480	3.9	-5.733
2.4	-5.951	4.0	-6.537	2.4	-1.512	4.0	-2.087	1.9	-3.029	4.0	-5.763
2.5	-6.040	4.1	-6.551	2.5	-1.567	4.1	-2.113	2.4	-4.826	4.1	-5.791
		4.2	-6.565					2.5	-4.938	4.2	-5.816

DATA TABLE 236. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MANGANESE BROMIDE TETRAHYDRATE $MnBr_2 \cdot 4H_2O$

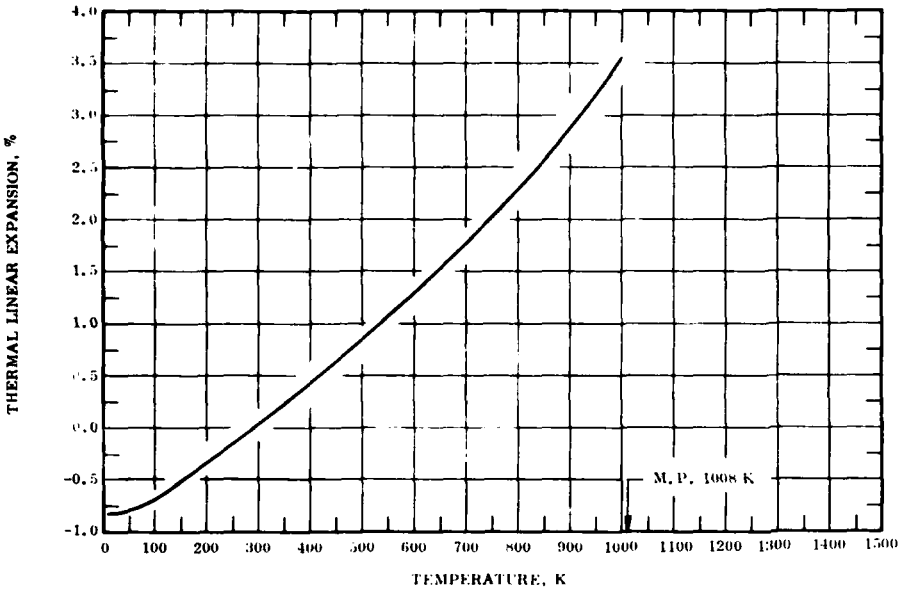
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α	T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 2*,‡		CURVE 2 (cont.)*,‡		CURVE 3*,‡		CURVE 3 (cont.)*,‡	
0.6	-0.31	2.6	-0.65	0.6	-0.08	2.6	-0.47	0.5	-0.16	2.6	-0.89
0.7	-0.51	2.7	-0.55	0.7	-0.14	2.7	-0.44	0.6	-0.26	2.7	-0.80
0.8	-0.75	2.8	-0.47	0.8	-0.22	2.8	-0.42	0.7	-0.44	2.8	-0.73
0.9	-1.01	2.9	-0.41	0.9	-0.30	2.9	-0.39	0.8	-0.65	2.9	-0.67
1.0	-1.34	3.0	-0.37	1.0	-0.39	3.0	-0.37	0.9	-0.88	3.0	-0.61
1.1	-1.70	3.1	-0.33	1.1	-0.49	3.1	-0.35	1.0	-1.15	3.1	-0.57
1.2	-2.13	3.2	-0.29	1.2	-0.59	3.2	-0.33	1.1	-1.45	3.2	-0.53
1.3	-2.62	3.3	-0.27	1.3	-0.69	3.3	-0.32	1.2	-1.78	3.3	-0.49
1.4	-3.16	3.4	-0.24	1.4	-0.82	3.4	-0.31	1.3	-2.16	3.4	-0.46
1.5	-3.81	3.5	-0.22	1.5	-0.95	3.5	-0.29	1.4	-2.58	3.5	-0.43
1.6	-4.54	3.6	-0.19	1.6	-1.10	3.6	-0.29	1.5	-3.05	3.6	-0.40
1.7	5.36	3.7	-0.18	1.7	-1.27	3.7	-0.28	1.6	-3.59	3.7	-0.37
1.8	-6.40	3.8	-0.17	1.8	-1.48	3.8	-0.28	1.7	-4.23	3.8	-0.34
1.9	-7.85	3.9	-0.16	1.9	-1.73	3.9	-0.27	1.8	-5.00	3.9	-0.31
2.4	-0.99	4.0	-0.15	2.4	-0.58	4.0	-0.26	1.9	-5.98	4.0	-0.29
2.5	-0.79	4.1	-0.14	2.5	-0.52	4.1	-0.26	2.4	-1.21	4.1	-0.26
		4.2	-0.13					2.5	-1.02	4.2	-0.24

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 237R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF POTASSIUM BROMIDE KBr



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
5	-0.823	0.01
25	-0.820	4.3
50	-0.794	16.7
75	-0.740	25.0
100	-0.673	28.6
150	-0.517	33.3
200	-0.345	35.7
250	-0.162	37.4
293	0.000	38.3
300	0.028	38.5
400	0.429	40.6
500	0.846	43.2
600	1.289	46.7
700	1.769	50.0
800	2.295	54.3
900	2.879	61.7
1000	3.532	72.4

REMARKS

The recommended values are based on the data for high purity sample and are considered accurate to within ±3% at temperatures below 600 K and ±5% above that. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -1.192 + 4.314 \times 10^{-3} T - 1.360 \times 10^{-6} T^2 + 1.770 \times 10^{-9} T^3 \qquad (293\text{-}1000\ K)$$

The tabulated values for the coefficient of thermal expansion are primarily based on the selected experimental data and are considered accurate to about ±7%.

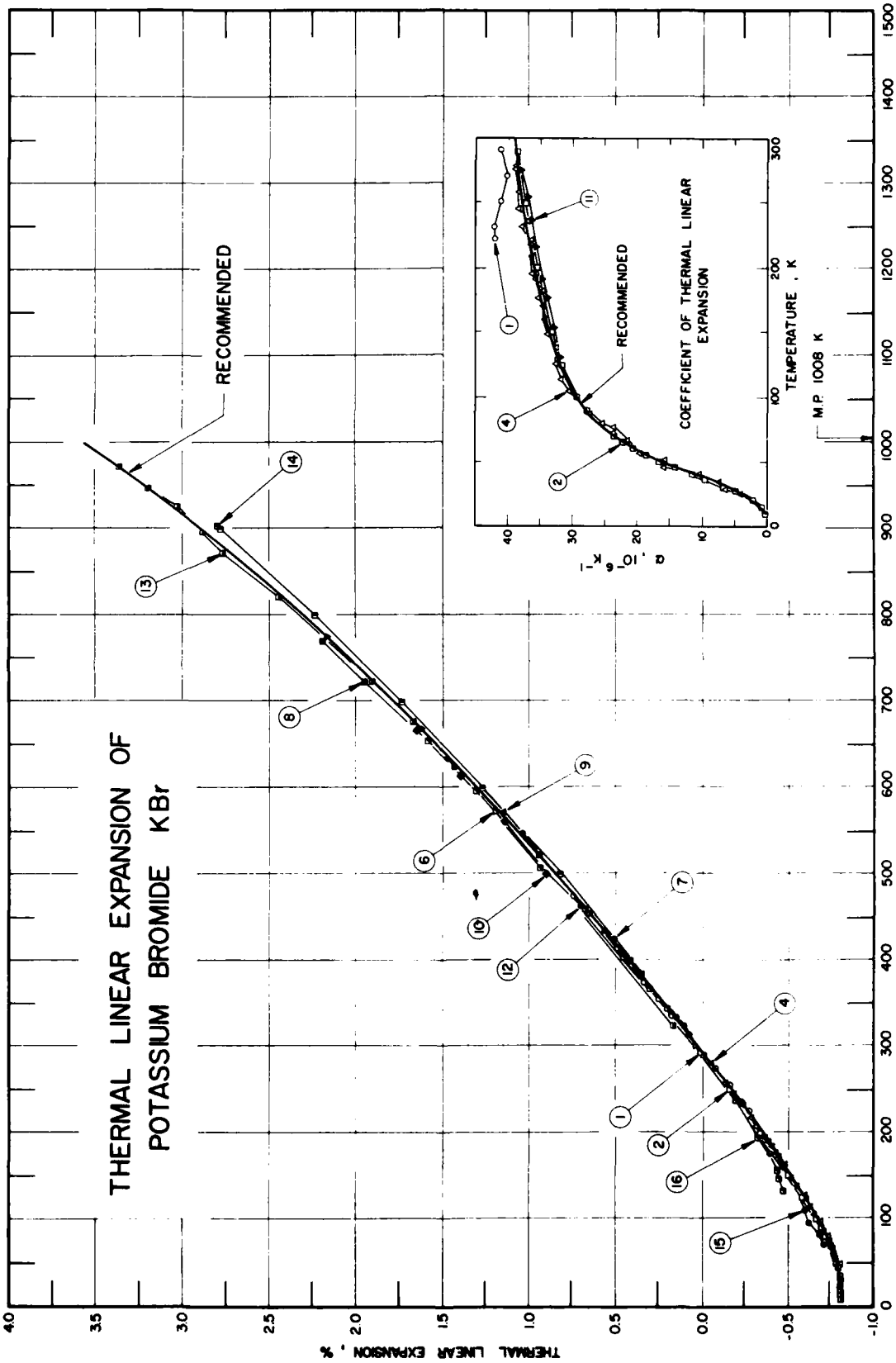

THERMAL LINEAR EXPANSION OF
POTASSIUM BROMIDE KBr
RECOMMENDED
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
α , 10⁻⁶ K⁻¹
TEMPERATURE , K
M.P. 1008 K

FIGURE 237

SPECIFICATION TABLE 237. THERMAL LINEAR EXPANSION OF POTASSIUM BROMIDE KBr

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	322	Combes, L. S., Ballard, S. S. and McCarthy, K. A.	1951	L	223-473		Bar specimen; furnished by the Harshaw Chemical Co., Cleveland, Ohio.
2	478	Meincke, P. P. M. and Graham, G. M.	1965	I	7-290		Specimen 2.54 cm diameter x 5.1 cm long, with axial hole of 1.3 cm diameter; supplied by Harshaw Chemical Co.; smoothed data; reported error <5%.
3*	479	White, G. K.	1965	E	5-85		Optical quality specimen obtained from Harshaw Chemical Co., Ohio; specimen cylinder 2 cm diameter, ~5 cm long; data smoothed by author; reported error 1.0%; this curve is here reported using the first given temperature (5 K) as reference temperature at which $\Delta L/L_0 = 0$.
4	480	Yates, B. and Panter, C. H.	1962	I	22-280		Single crystal obtained from Hilger and Watts Ltd., London; grown from 99.6 pure material; expansion observed with cadmium green light (5085.8 Å).
5*	481	McKinstry, H. A.	1960	X	299-670		Powdered specimen from single crystal; lattice parameter reported at 299.40 K as 6.59515 Å; 6.57882 Å at 293.15 K determined by graphical extrapolation; reported error <2%.
6	481	McKinstry, H. A.	1960	X	301-773		The above specimen; second run; lattice parameter reported at 300.90 K as 6.59896 Å; 6.59693 Å at 293.15 K determined by graphical extrapolation; reported error <2%.
7	481	McKinstry, H. A.	1960	X	302-474		Similar to the above specimen; single crystal cleaved surface; lattice parameter reported at 301.90 K as 6.59873 K; 6.59654 Å at 293.15 K determined by graphical extrapolation; reported error <2%.
8	481	McKinstry, H. A.	1960	X	298-773		The above specimen; second run; lattice parameter reported at 298.40 K as 6.59844 Å; 6.59801 Å at 293.15 K determined by graphical extrapolation; reported error <2%.
9	481	McKinstry, H. A.	1960	X	299-573		Similar to the above specimen; freshly cleaved surface of single crystal; lattice parameter reported at 299.2 K as 6.59696 Å; 6.59548 Å at 293 K determined by graphical extrapolation; reported error <2%.
10	481	McKinstry, H. A.	1960	O	297-668		Specimen of single crystal obtained from Harshaw Co.; reported error <2%.
11*	482	Srinivasan, R.	1956		114-571		Specimen cut from single transparent crystal grown from melt.
12	483	Connell, L. F. and Martin, H. C. Jr.	1951	X	291-463		99.99 pure specimen prepared from C. P. Baker's analyzed sample; expansion measured using $FeK\alpha_1$ and $CuK\alpha_1$ x-radiations.
13	628	Pathak, P. D., Trivedi, J. M., and Vasavada, N. G.	1973	X	273-973		Powder specimen.
14	625	Srivastava, K. K. and Merchant, H. D.	1972	X	293-904		No details given.
15	626	Rapp, J. E. and Merchant, H. D.	1972	L	70-571		Crystal orientation was <1,0,0>; dimensions were 5 x 5 x 50 mm; smoothed data.
16	626	Von Trost, K. F.	1963		131-655		No details given.
17*	664	Whittemore, D. O.	1962	L	293,593		Dimensions 1.3 cm diameter x 2.54 cm cylinder; specimen made by pressing reagent grade chemicals in a steel mold at 10,000 psi; original length measured by micrometer to 0.025 mm; the specimen consisted of two cylinders.
18*	624	Rapp, J.	1969	L	83-573		Rectangular bar 5 x 5 x 50 mm; specimen obtained from Harshaw Chemical Co. of Ohio.

* Not shown in figure.

DATA TABLE 237. THERMAL LINEAR EXPANSION OF POTASSIUM BROMIDE KBr

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1 ‡	
223	-0.287
233	-0.245
253	-0.162
273	-0.081
293	0.000
313	0.086
333	0.175
353	0.258
373	0.333
393	0.407
413	0.486
433	0.569
453	0.654
473	0.743
CURVE 2 ‡	
7	-0.822*
8	-0.822*
9	-0.822*
10	-0.822
11	-0.822*
12	-0.822*
14	-0.822*
15	-0.822
16	-0.822*
17	-0.822*
18	-0.822*
19	-0.821*
20	-0.821
22	-0.821*
24	-0.820*
26	-0.819
28	-0.818*
30	-0.817
32	-0.815*
34	-0.814*
36	-0.812
38	-0.810*
40	-0.808*
45	-0.801
50	-0.794
55	-0.785
60	-0.775
65	-0.764
70	-0.753

T	$\Delta L/L_0$
CURVE 2 (cont.) ‡	
80	-0.728
90	-0.701
100	-0.673
125	-0.597
150	-0.516
200	-0.344
250	-0.163
290	-0.011
CURVE 3*, †, ‡	
5	0.0000000
6	0.0000018
7	0.0000053
8	0.0000111
10	0.000034
12	0.000085
14	0.000183
16	0.000349
18	0.000608
20	0.000987
22	0.00151
24	0.00219
26	0.00305
28	0.00411
30	0.00537
65	0.0566
75	0.0803
85	0.106
CURVE 4 ‡	
22	-0.825*
25	-0.824*
28	-0.822*
34	-0.818*
36	-0.817*
37	-0.816*
40	-0.813*
43	-0.809*
43	-0.809*
46	-0.805*
46	-0.805*
48	-0.802*
49	-0.801*
49	-0.801*

T	$\Delta L/L_0$
CURVE 4 (cont.) ‡	
52	-0.796*
56	-0.790*
56	-0.790*
59	-0.784*
59	-0.784*
63	-0.775*
64	-0.773*
68	-0.765
68	-0.765*
72	-0.756*
72	-0.756
76	-0.746
80	-0.736
87	-0.718
90	-0.710*
99	-0.684
105	-0.667
107	-0.661*
114	-0.639
122	-0.614
126	-0.601*
129	-0.591*
138	-0.563
149	-0.526*
163	-0.479
171	-0.451
176	-0.434
184	-0.406
187	-0.396*
190	-0.385
195	-0.367
203	-0.338*
208	-0.320
217	-0.288
221	-0.273*
232	-0.233*
235	-0.222*
245	-0.184
249	-0.169*
258	-0.135
277	-0.062*
280	-0.050
CURVE 5*	
299.40	0.248

T	$\Delta L/L_0$
CURVE 5 (cont.)*	
300.90	0.307
373.15	0.596
473.65	1.030
572.90	1.479
669.90	1.952
CURVE 6	
300.90	0.030
373.15	0.318
473.65	0.752*
572.90	1.197
669.65	1.674
772.95	2.178
CURVE 7	
301.90	0.033*
332.15	0.148
423.15	0.525
473.90	0.749*
CURVE 8	
298.40	0.006
301.90	0.010*
302.15	0.024*
474.65	0.732
522.65	0.946
572.40	1.181*
623.55	1.424
671.90	1.673
723.95	1.942
770.65	2.183
772.55	2.197*
CURVE 9	
299.20	0.022*
385.20	0.343
375.65	0.303*
472.75	0.708
572.40	1.146
573.20	1.154*

T	$\Delta L/L_0$
CURVE 10	
296.83	0.014*
356.72	0.256*
395.22	0.417*
452.39	0.658*
506.44	0.897
561.51	1.145
615.34	1.390
667.85	1.645
CURVE 11*, ‡	
114.3	-0.622
133.4	-0.562
154.2	-0.495
176.2	-0.422
196.2	-0.354
216.4	-0.283
236.2	-0.212
255.9	-0.141
276.5	-0.064
318.7	0.099
355.0	0.245
390.2	0.391
424.2	0.538
457.0	0.684
487.1	0.822
518.0	0.966
547.4	1.108
571.3	1.225
CURVE 12	
291	-0.008*
373	0.324
463	0.709
CURVE 13 ‡	
273	-0.078*
323	0.116
373	0.316*
423	0.521
473	0.732*
523	0.951
573	1.176*
623	1.410*

T	$\Delta L/L_0$
CURVE 13 (cont.) ‡	
673	1.652
723	1.903
773	2.164*
823	2.434
873	2.719
898	2.868
923	3.024
948	3.186
973	3.356
CURVE 14 ‡	
293	0.000*
300	0.026*
400	0.410
500	0.823
600	1.267
700	1.743
800	2.248
900	2.783
904	2.805
CURVE 15 ‡	
70	-0.720
82	-0.690
95	-0.656
111	-0.612
122	-0.580*
146	-0.508*
174	-0.418
196	-0.345*
221	-0.260*
247	-0.168*
293	0.000*
296	0.011*
322	0.109
421	0.493
473	0.704*
549	1.034
571	1.136*
CURVE 16 ‡	
131	-0.495
143	-0.465

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 237. THERMAL LINEAR EXPANSION OF POTASSIUM BROMIDE KBr (continued)

T	$\Delta L/L_0$
CURVE 16 (cont.)‡	
153	-0.440
193	-0.330
238	-0.193
274	-0.070*
280	-0.049*
293	0.000*
303	0.039*
304	0.043
314	0.083*
343	0.201
369	0.307
404	0.451
414	0.492*
460	0.685
508	0.891
599	1.305
655	1.577
CURVE 17*	
293	0.00
593	1.33
CURVE 18*,‡	
83	-0.691
93	-0.664
113	-0.608
123	-0.579
148	-0.504
173	-0.424
198	-0.340
223	-0.254
248	-0.165
273	-0.074
298	0.019
323	0.113
373	0.305
423	0.503
475	0.716
523	0.922
548	1.034
573	1.150

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 237. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POTASSIUM BROMIDE KBr

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

CURVE 1 ‡

T	α
223	42
233	42
253	41
273	40
293	41
313	45*
333	44*
353	39*
373	36*
393	38*
413	41*
433	42*
453	43*
473	44*

CURVE 2 ‡

T	α
7	0.042*
8	0.066*
9	0.106*
10	0.162
11	0.249*
12	0.364*
14	0.66*
15	0.83
16	1.03*
17	1.25*
18	1.51*
19	1.80*
20	2.13
22	2.91*
24	3.79*
26	4.73
28	5.78*
30	6.83
32	7.86*
34	8.80*
36	9.61
38	10.56*
40	11.62
45	14.27
50	16.69
55	18.69
60	20.51
65	22.09
70	23.52

CURVE 2 (cont.) ‡

T	α
80	25.88
90	27.78
100	29.29
125	31.62
150	33.16
200	35.35
250	37.16
290	38.69

CURVE 3*, ‡

T	α
5	0.012
6	0.025
7	0.044
8	0.072
10	0.16
12	0.35
14	0.63
16	1.03
18	1.56
20	2.23
22	3.0
24	3.8
26	4.8
28	5.8
30	6.8
65	22.5
75	25.0
85	27.2

CURVE 4 ‡

T	α
22	2.1*
25	4.0
28	6.2
34	7.2
36	9.7*
37	7.8*
40	10.4
43	16.3*
43	13.9*
46	15.9
46	13.2*
48	12.0*
49	16.3*
49	14.7*

CURVE 4 (cont.) ‡

T	α
52	15.6
56	18.5*
56	19.5
59	18.8*
59	19.9*
63	21.5
64	20.5*
68	21.5
68	22.3*
72	23.5
72	25.0*
76	23.5
80	25.2
87	27.4
90	27.4
99	28.7*
105	30.5
107	29.8*
114	31.8
122	31.5*
126	32.5
129	31.4*
138	32.4
149	33.6
163	34.3
171	34.6
176	35.1
184	34.4
187	35.3
190	35.5
195	36.1
203	35.8*
208	36.1
217	36.1
221	36.2
232	37.8
235	36.9
245	38.2
249	37.6*
258	38.2
277	38.7
280	38.7

CURVE 11*, ‡

T	α
114.3	31.1
133.4	31.9
154.2	32.8
176.2	33.6
196.2	34.5
216.4	35.3
236.2	36.1
255.9	36.9
276.5	37.7
318.7	39.5*
355.0	40.7*
390.2	42.6*
424.2	43.8*
457.0	45.2*
487.1	46.2*
518.0	47.4*
547.4	48.7*
571.3	49.7*

CURVE 11 (cont.)*, ‡

CURVE 13*, ‡

T	α
273	38.30
323	39.30
373	40.40
423	41.60
473	43.00
523	44.40
573	45.90
623	47.60
673	49.30
723	51.10
773	53.00
823	55.20
873	58.70
898	60.90
923	63.50
948	66.40
973	69.60

CURVE 14*, ‡

T	α
293	36.60
300	37.10
400	39.80
500	42.80
600	46.00
700	49.10
800	51.90
900	55.10
904	55.30

CURVE 14 (cont.)*, ‡

CURVE 15*, ‡

T	α
70	24.4
82	25.8
95	26.9
111	28.1
122	29.3
146	31.1
174	32.7
196	33.8
221	34.7
247	35.8
293	37.2
296	37.3
322	37.8
421	39.8
473	41.4
549	45.4
571	47.2

CURVE 16*, ‡

T	α
131	24.2
143	24.7
153	25.5
193	29.7
238	31.3
274	36.7
280	35.8
293	38.9
303	39.4
304	40.3
314	40.3
343	40.6
369	41.1
404	41.3
414	41.3
460	42.3
508	43.6
599	47.5
655	49.4

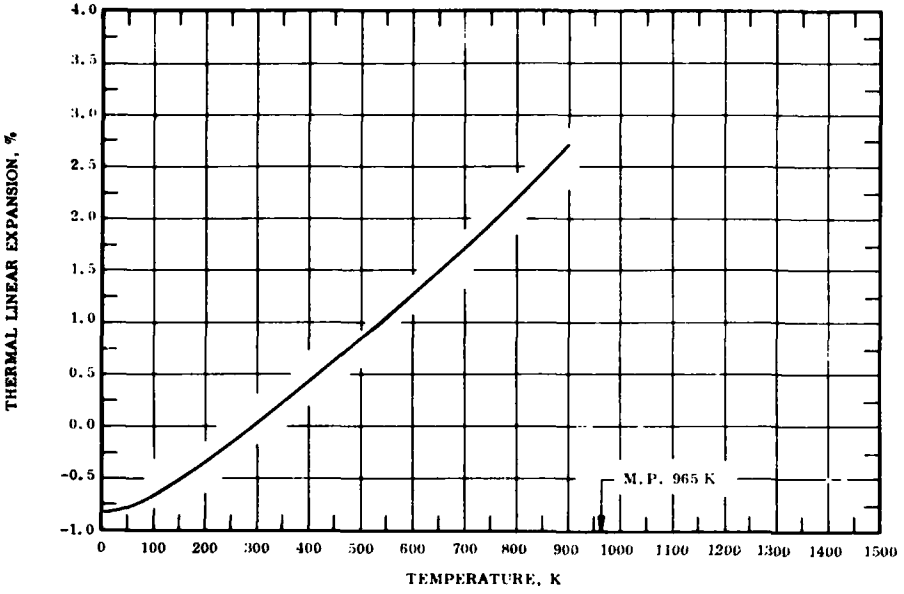
CURVE 18*, ‡

T	α
83	25.86
93	27.30
113	28.61
123	29.42
148	31.22
173	32.74
198	34.02
223	35.09
248	35.98
273	36.73
298	37.37
323	37.94
373	39.00
423	40.18
475	41.78
523	44.08
548	45.58
573	47.36

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 238R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF RUBIDIUM BROMIDE RbBr



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
3	-0.825	-0.001
5	-0.825	-0.005
10	-0.825	0.1
25	-0.820	6.2
50	-0.786	20.5
75	-0.725	26.5
100	-0.655	29.1
150	-0.503	32.2
200	-0.335	34.4
250	-0.158	36.2
293	0.000	37.5
300	0.027	37.7
400	0.421	40.1
500	0.829	42.3
600	1.258	44.1
700	1.713	46.4
800	2.197	49.9
900	2.716	55.8

REMARKS

The recommended values are based on the data for high purity samples are are considered accurate to about ± 5%. These values can be represented approximately by the following equations:

$$\Delta L/L_0 = -0.898 + 1.921 \times 10^{-3}\ T + 5.703 \times 10^{-6}\ T^2 - 6.164 \times 10^{-9}\ T^3 \quad (50\text{-}293\ K)$$

$$\Delta L/L_0 = -1.111 + 3.785 \times 10^{-3}\ T - 2.176 \times 10^{-7}\ T^2 + 8.180 \times 10^{-10}\ T^3 \quad (293\text{-}900\ K)$$

The tabulated values for the coefficient of thermal expansion are based on the experimental data and are considered accurate to about ± 7%.

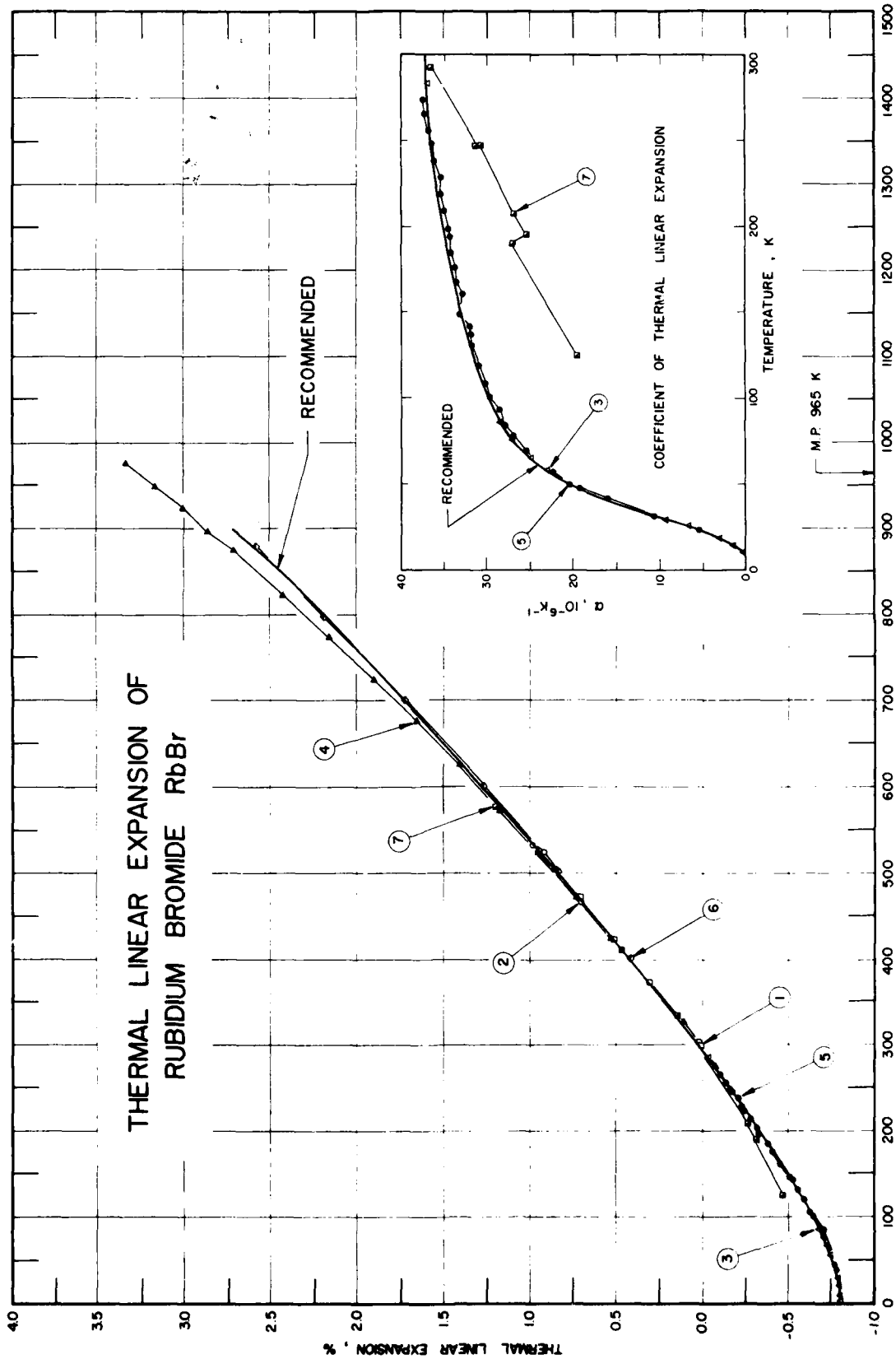

THERMAL LINEAR EXPANSION OF
RUBIDIUM BROMIDE RbBr
RECOMMENDED
M.P. 965 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
α , 10⁻⁶K⁻¹
TEMPERATURE , K

FIGURE 238

SPECIFICATION TABLE 238. THERMAL LINEAR EXPANSION OF RUBIDIUM BROMIDE RbBr

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	481	McKinstry, H.A.	1960	X	298-473		Specimen prepared from a chemically pure $RbCO_3$ and chemically pure hydrobromic acid; < 1% potassium, < 2% chlorine indicated by x-ray fluorescence analysis; first run; lattice parameter reported at 298.15 K as 6.87357 Å; 6.87224 Å at 293 K determined by graphical extrapolation.
2	481	McKinstry, H.A.	1960	X	300-533		The above specimen; second run; lattice parameter reported at 300.95 K as 6.87410 Å; 6.87224 Å at 293 K determined by graphical extrapolation.
3	623	White, G.K. and Collins, J.G.	1973	E	3-283		Cylindrical specimen; 20 mm diameter x 50.8 mm long; specimen obtained from Semi-Elements Inc. of Pennsylvania; this curve is here reported utilizing other coefficients of linear expansion from 85 K to 283 K for integration purposes.
4	628	Pathak, P.D., Trivedi, J.M., and Vasavada, N.G.	1973	X	273-973		Powder specimen.
5	629	James, B.W. and Yates, B.	1964	I	23.6-273.7		Single crystal specimen obtained from L. Light & Co., Ltd.; 0.005 impurity, consisted of a hollow cylinder 2.7 cm O.D., 1.8 cm I.D., and 1 cm high.
6	625	Srivastava, K.K. and Merchant, H.D.	1972	X	293-881		No details given.
7	663	Von Trost, K.F.	1963		125-577		No details given.

DATA TABLE 238. THERMAL LINEAR EXPANSION OF RUBIDIUM BROMIDE RbBr

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298.15	0.01935
302.90	0.03768*
373.90	0.30790
422.66	0.51438
472.40	0.71912
CURVE 2	
300.95	0.02706*
467.95	0.70093
525.20	0.93768
533.95	0.98454
CURVE 3‡	
3.493	-0.825*
4.004	-0.825*
4.410	-0.825*
4.854	-0.825*
4.907	-0.825
5.465	-0.825*
5.541	-0.825*
6.024	-0.825*
6.119	-0.825*
6.592	-0.825*
7.108	-0.825*
7.656	-0.825*
8.373	-0.825*
9.043	-0.825*
9.682	-0.825*
10.578	-0.825
11.414	-0.825*
12.389	-0.825*
13.646	-0.825*
14.884	-0.825
16.185	-0.825*
17.654	-0.825*
19.283	-0.824*
21.047	-0.824
23.075	-0.823*
25.159	-0.821
27.122	-0.820*
29.022	-0.818
57.500	-0.773
65.0	-0.755
75.0	-0.729
CURVE 3 (cont.)‡	
85.0	-0.701
283.0	-0.036
CURVE 4‡	
273	-0.078
323	0.116
373	0.316*
423	0.521
473	0.732
523	0.951
573	1.176
623	1.410
673	1.652
723	1.903
773	2.164
823	2.434
873	2.719
898	2.868
923	3.024
948	3.186
973	3.356
CURVE 5‡	
23.6	-0.818
26.5	-0.816*
30.5	-0.812
37.8	-0.803*
40.9	-0.799
46.9	-0.788
50.0	-0.782*
56.8	-0.763*
59.5	-0.761
67.0	-0.743*
69.0	-0.738*
77.7	-0.715*
82.1	-0.703
84.3	-0.697
87.5	-0.688*
93.1	-0.672
96.4	-0.663*
100.4	-0.651
108.7	-0.626
119.0	-0.595
120.0	-0.591*
CURVE 5 (cont.)‡	
127.5	-0.568*
130.6	-0.558
136.6	-0.539*
141.1	-0.524
145.2	-0.511
149.5	-0.497*
153.9	-0.483*
160.1	-0.458
164.3	-0.448*
167.6	-0.437*
172.5	-0.420*
175.5	-0.410
181.2	-0.391*
184.5	-0.380
189.3	-0.363*
193.7	-0.348*
198.7	-0.331
204.3	-0.311
208.8	-0.296
213.7	-0.278
218.3	-0.262*
223.0	-0.245
229.0	-0.224
233.4	-0.221*
237.9	-0.205
244.1	-0.183*
249.8	-0.162
253.6	-0.148*
255.7	-0.140
265.2	-0.105
273.7	-0.073*
CURVE 6‡	
293	0.000
300	0.027*
400	0.427
500	0.842
600	1.273
700	1.721
800	2.185
881	2.570
CURVE 7‡	
125	-0.469
CURVE 7 (cont.)‡	
190	-0.317
195	-0.304*
208	-0.269
247	-0.157*
247	-0.157*
293	0.000*
324	0.117*
332	0.148
335	0.160
410	0.463
505	0.869
577	1.198

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 238. COEFFICIENT OF THERMAL LINEAR EXPANSION OF RUBIDIUM BROMIDE RbBr

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3‡	
3.493	-0.0013*
4.004	-0.0016*
4.410	-0.0026*
4.854	-0.0042*
4.907	-0.0054*
5.465	-0.0067*
5.541	-0.0034*
6.024	-0.0084*
6.119	-0.0092*
6.592	-0.0115*
7.108	-0.0107*
7.656	-0.0058*
8.373	0.0069*
9.043	0.0288*
9.682	0.0621*
10.578	0.1349
11.414	0.2295*
12.389	0.3874*
13.646	0.6693*
14.884	1.023
16.185	1.510*
17.654	2.133*
19.283	2.979
21.047	3.976*
23.075	5.282*
25.159	6.667
27.122	8.012*
29.022	9.263
57.500	22.919
65.0	24.929
75.0	26.83
85.0	28.36
283.0	36.96
CURVE 4*,‡	
273	38.3
323	39.3
373	40.4
423	41.6
473	43.0
523	44.4
573	45.9
623	47.6
673	49.3
723	51.1

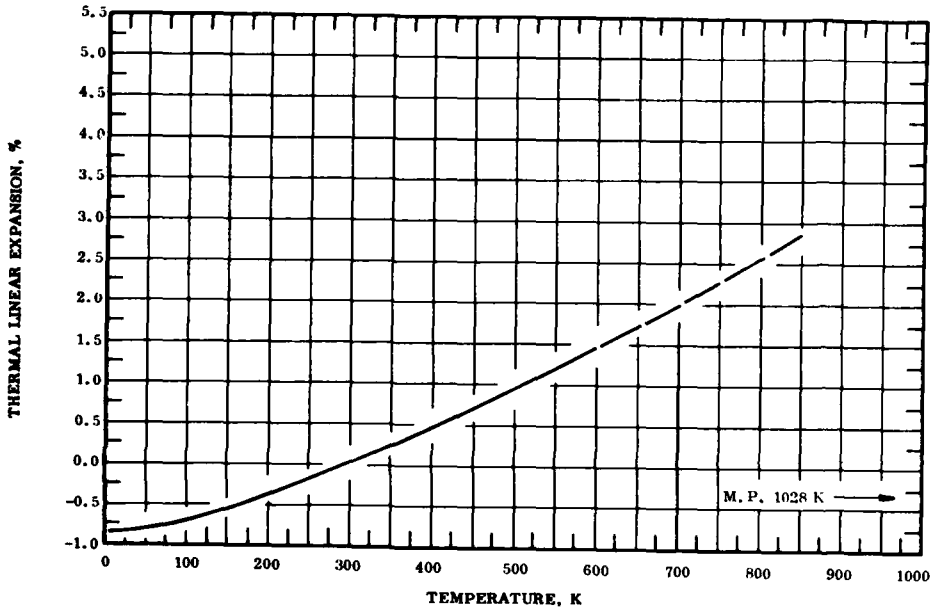
T	α
CURVE 4 (cont.)*,‡	
773	53.0
823	55.2
873	59.7
898	60.9
923	63.5
948	66.4
973	69.6
CURVE 5‡	
23.6	5.5
26.5	7.6*
30.5	10.6
37.8	14.4*
40.9	16.0
46.9	19.3
50.0	20.3
56.8	22.6
59.5	23.1*
67.0	24.8*
69.0	25.5
77.7	26.9
82.1	27.5*
84.3	27.9
87.5	28.2*
93.1	28.6
96.4	29.4*
100.4	29.7
108.7	30.3
119.0	31.1*
120.0	30.9
127.5	32.1*
130.6	31.8
136.6	31.8
141.1	32.1
145.2	32.2*
149.5	33.2
153.9	33.3*
160.1	32.9
164.3	33.5*
167.6	33.7
172.5	33.7*
175.5	33.8
181.2	34.3*
184.5	34.3
189.3	34.4*

T	α
CURVE 5 (cont.)‡	
193.7	34.4
198.7	34.6
204.3	34.8*
208.8	35.1
213.7	35.6*
218.3	35.6
223.0	35.2*
229.0	35.4
233.4	35.7*
237.9	36.3
244.1	36.4*
249.8	36.4
253.6	36.7*
255.7	36.9
265.2	37.3
273.7	37.4
CURVE 6*,‡	
293	39.1
300	39.4
400	40.6
500	42.3
600	43.9
700	45.7
800	47.1
881	47.9
CURVE 7‡	
125	19.7
190	27.1
195	25.7
208	26.9
247	30.8
247	31.5
293	36.7
324	38.7*
332	39.2*
335	39.6*
410	41.2*
505	44.4*
577	46.8*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 239R. *RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SODIUM BROMIDE* NaBr



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
5	-0.858	0.02
10	-0.857	0.20
25	-0.851	4.0
50	-0.836	14.2
75	-0.778	24.7
100	-0.710	29.7
150	-0.551	34.5
200	-0.370	37.6
250	-0.173	40.0
293	0.000	41.6
300	0.029	41.8
350	0.241	43.4
400	0.461	44.8
450	0.689	46.2
500	0.925	48.0
550	1.171	50.0
600	1.427†	52.2†
650	1.693†	54.5†
700	1.970†	56.7†
750	2.259†	59.1†
800	2.560†	61.5†
850	2.875†	63.8†

† Provisional values.

REMARKS

The recommended values are based on the data for high purity samples and are based on the measurements which are consistent for low and high temperature region. The provisional values above 600 K are extrapolated. These values are considered accurate to within ±4% at temperatures below 600 K and ±4% above that and are represented approximately by the following equations:

$$\Delta L/L_0 = -0.922 + 1.243 \times 10^{-3}\, T + 9.959 \times 10^{-6}\, T^2 - 1.182 \times 10^{-8}\, T^3 \quad (50\text{-}300\ K)$$

$$\Delta L/L_0 = -1.124 + 3.589 \times 10^{-3}\, T + 6.047 \times 10^{-7}\, T^2 + 8.330 \times 10^{-10}\, T^3 \quad (293\text{-}850\ K)$$

The tabulated values for the coefficient of thermal expansion are based on the experimental data and are considered accurate to about ±10%.

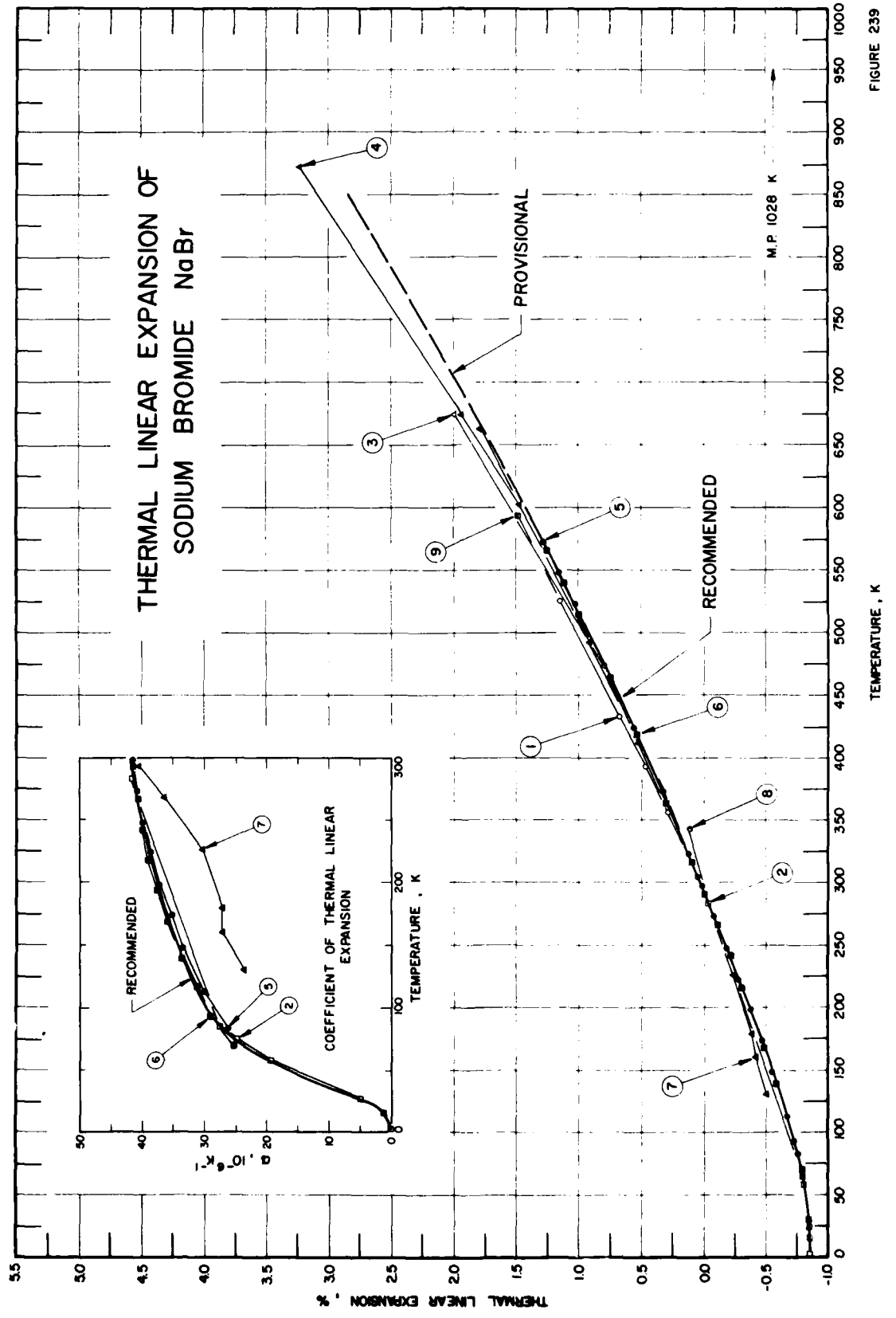

THERMAL LINEAR EXPANSION OF
SODIUM BROMIDE NaBr
PROVISIONAL
RECOMMENDED
M.P. 1028 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
α , 10⁻⁶ K⁻¹
TEMPERATURE , K

FIGURE 239

SPECIFICATION TABLE 239. THERMAL LINEAR EXPANSION OF SODIUM BROMIDE NaBr

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	799	Deshpande, V.T.	1961	X	304-525		No information given.
2	623	White, G.K. and Collins, J.G.	1973	E	3-283		Cylindrical specimen; 20 mm diameter x 50.8 mm long; specimen optical quality from Harshaw Chemicals of Ohio; this curve is here reported utilizing other coefficients of thermal linear expansion from 85 K to 283 K for integration purposes.
3	970	Chin, T.L. and Sik, F.	1972	X	473, 673		Normal cubic cell was measured (α phase); lattice parameter reported at 473 K as 12.043 Å; 11.9134 Å at 293 K determined by graphical extrapolation.
4	970	Chin, T.L. and Sik, F.	1972	X	603-873		The above specimen; β-phase; specimen had a doubled cubic cell lattice parameter reported at 603 K as 12.133 Å; 11.9410 Å at 293 K determined by graphical extrapolation.
5	624	Rapp, J.	1969	L	83-573		Dimensions 5 x 5 x 50 mm; single crystal specimen obtained from Semi-Elements Inc. of Pennsylvania.
6	626	Rapp, J.E. and Merchant, H.D.	1972	L	70-566		Crystal orientation < 1, 0, 0>; dimensions were 5 x 5 x 50 mm; smoothed data.
7	663	Von Trost, K.F.	1963		131-663		No details given.
8	665	Johnson, R.W.	1967		293, 343		No details given.
9	664	Whittemore, D.O.	1962		293, 593		Dimensions: 1.27 cm diameter x 2.54 cm long cylinder specimen made by pressing reagent grade chemicals in a steel mold at 10,000 psi; length measured by micrometer to within 0.051 mm; specimen measured consisted of two cylinders.

DATA TABLE 239. THERMAL LINEAR EXPANSION OF SODIUM BROMIDE NaBr

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %].

T	$\Delta L/L_0$
CURVE 1	
304.7	0.053
355.9	0.289
392.6	0.467
433.2	0.676
525.2	1.143
CURVE 2‡	
2.877	-0.860
3.498	-0.860*
4.008	-0.860*
4.455	-0.860*
4.903	-0.860*
5.341	-0.860*
5.718	-0.860*
6.072	-0.860*
6.448	-0.860*
6.862	-0.860*
7.357	-0.860*
7.934	-0.859*
8.663	-0.859*
9.484	-0.859*
10.310	-0.859*
11.008	-0.859*
11.587	-0.859*
12.655	-0.859*
14.183	-0.859*
15.687	-0.859
17.217	-0.859*
18.964	-0.859
20.855	-0.858*
22.845	-0.858*
26.940	-0.856*
28.810	-0.855*
30.270	-0.854
58	-0.818
65	-0.804
75	-0.780
85	-0.754
283	-0.041
CURVE 3	
473	0.00
673	1.20

T	$\Delta L/L_0$
CURVE 4	
603	0.00
673	0.46
873	1.74*
CURVE 5‡	
83	-0.753
93	-0.725
113	-0.667
123	-0.636*
148	-0.555
173	-0.469
198	-0.377
223	-0.282
248	-0.184
273	-0.083
298	0.021
323	0.126
373	0.341
423	0.562
475	0.800*
523	1.031
548	1.157
573	1.287
CURVE 6‡	
70	-0.797
80	-0.771*
93	-0.735*
110	-0.684*
117	-0.663*
139	-0.591
168	-0.491
193	-0.399*
217	-0.307
242	-0.208
267	-0.107
291	-0.008*
293	0.000*
316	0.097
365	0.308
418	0.542
464	0.751
515	0.995
540	1.120
566	1.255

T	$\Delta L/L_0$
CURVE 7‡	
131	-0.497
161	-0.421
189	-0.372
226	-0.237
268	-0.097*
293	0.000*
356	0.274*
413	0.541
492	0.923
663	1.793
CURVE 8	
293	0.000*
343	0.120
CURVE 9	
293	0.00*
593	1.49

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 239. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM BROMIDE NaBr

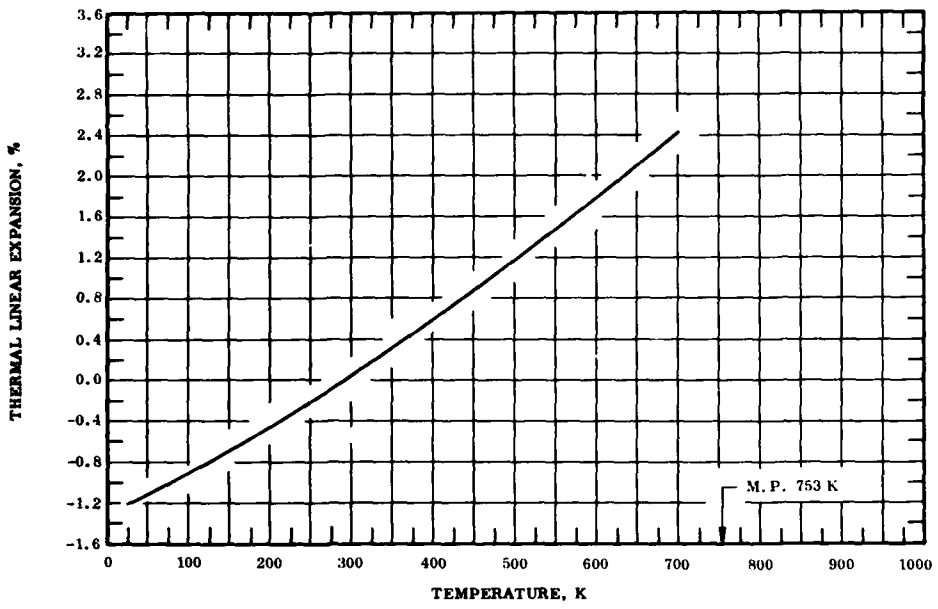
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 2‡	
2.877	0.003
3.498	0.006*
4.008	0.009*
4.455	0.014*
4.903	0.021*
5.341	0.027*
5.718	0.033*
6.072	0.041*
6.448	0.051*
6.862	0.061*
7.357	0.077*
7.934	0.099*
8.663	0.133*
9.484	0.184*
10.310	0.246*
11.008	0.309*
11.587	0.373*
12.655	0.517*
14.183	0.774*
15.687	1.104
17.217	1.452*
18.964	1.960*
20.855	2.575*
22.845	3.303*
26.940	4.910
28.810	5.874*
30.270	6.470*
58	19.3
65	21.9*
75	24.97
85	27.50
283	41.71
CURVE 5‡	
83	26.38
93	28.32*
113	30.10
123	31.19*
148	33.63
173	35.68
198	37.39
223	38.80
248	39.96
273	40.91
298	41.71

T	α
CURVE 5 (cont.)‡	
323	42.39*
373	43.60*
423	44.92*
475	46.73*
523	49.38*
548	51.16*
573	53.23*
CURVE 6‡	
70	25.3
80	26.8*
93	29.2
110	30.4*
117	31.2
139	33.6
168	35.9
193	37.6
217	39.0
242	39.9
267	40.8
291	41.7*
293	41.8
316	42.5*
365	43.5*
418	44.8*
464	46.4*
515	49.2*
540	50.8*
566	52.6*
CURVE 7‡	
131	23.7
161	27.1
179	27.1
226	30.3
268	36.6
293	40.9
356	46.1*
413	47.7*
492	48.9*
663	52.9*

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 240R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF THALLIUM BROMIDE TlBr



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
25	-1.222	22.9
50	-1.209	36.5
75	-1.045	41.1
100	-0.939	43.6
150	-0.713	46.7
200	-0.473	49.1
250	-0.223	51.1
293	0.000	52.4
350	0.303	54.1
400	0.578	55.6
500	1.151	59.1
600	1.761	62.8
700	2.408	66.9

REMARKS

The recommended values are based on the data for high purity powder samples and are based on the most recent measurements. These values are considered accurate to within ± 5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -1.394 + 4.296 \times 10^{-3} T + 1.538 \times 10^{-6} T^2 + 1.143 \times 10^{-10} T^3 \qquad (150\text{-}700\ K)$$

The tabulated values for the coefficient of thermal expansion are based on the experimental data at temperatures below 260 K and above 260 K, the values are derived by differentiating the above equation. These values are considered accurate to about ± 5%.

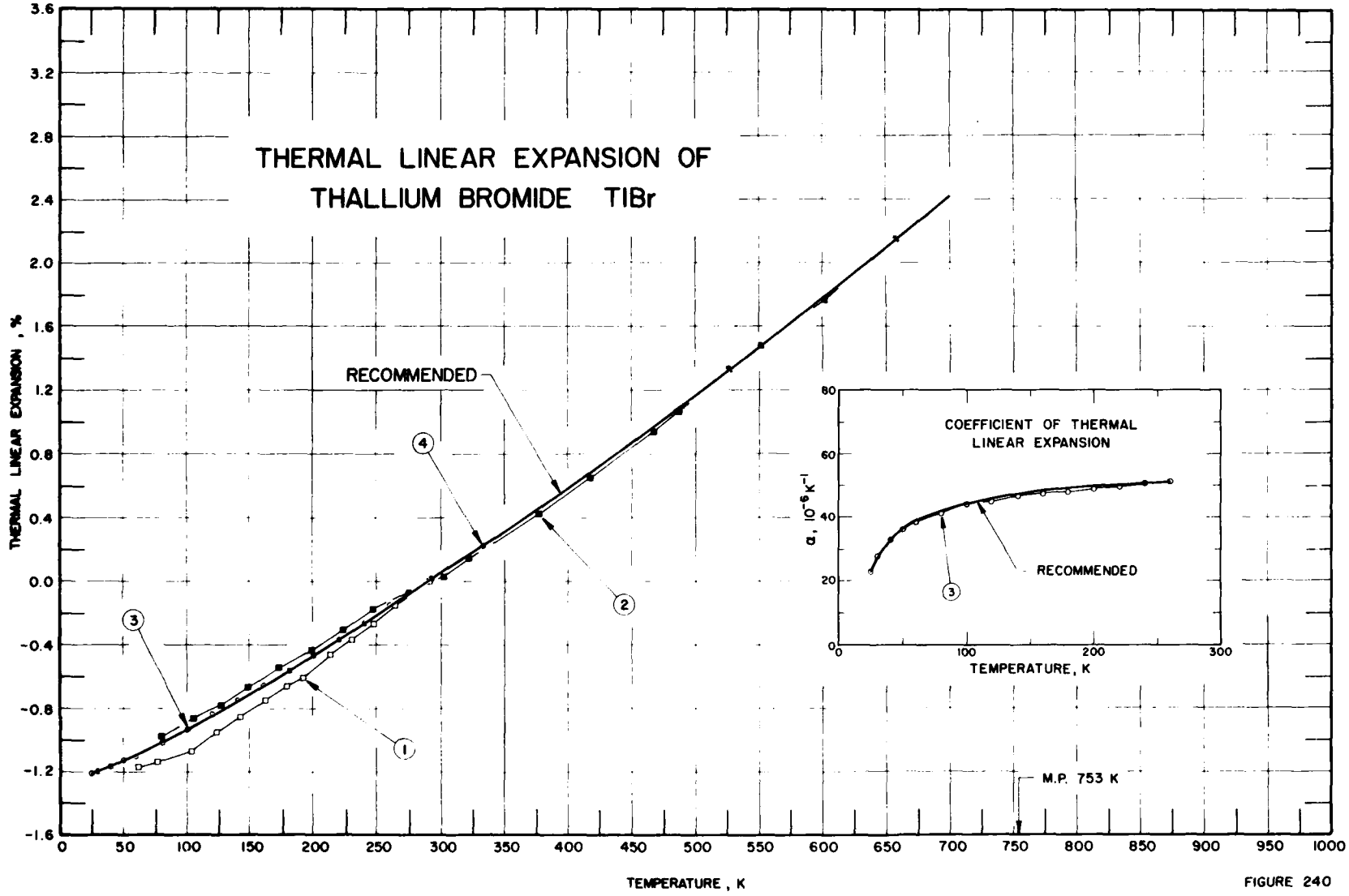

THERMAL LINEAR EXPANSION OF
THALLIUM BROMIDE TlBr
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED
M.P. 753 K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
α, 10⁻⁶ K⁻¹
TEMPERATURE, K
RECOMMENDED

FIGURE 240

SPECIFICATION TABLE 240. THERMAL LINEAR EXPANSION OF THALLIUM MONOBROMIDE TlBr

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	666	Vallin, J., Marklund, K., and Sikstrom, J.O.	1966	X	62-293		Single crystal of high purity cubed specimen of 1 cm^3, obtained from Semi-Elements Inc.; crystal ground on a glass plate with 1000 grade carborundum and kerosene; washed in acetone, between transducer and specimen bounded under dry helium gas; lattice parameter reported at 293 K is 3.9846 Å.
2	667	Morse, G.E. and Lawson, A.W.	1967		80-658		Sample was flycut; surfaces were smooth, flat and parallel; obtained from Semi-Elements Inc., Saxonburg, Pa.; expansion measured by micro cavity method at 9000 MHZ; zero-point correction is 0.034% at 293 K determined by graphical interpolation.
3	668	Redmond, A.D. and Yates, B.	1972	X	25-260		Single crystals from New Metals and Chemical Ltd., with purity 99.995; dimensions: 3 x 3 x 10 mm; measurements made with long axis vertical; smooth values were given; reported error is 6% from 25-50 K and 2% from 50-270 K.
4	665	Johnson, R.W.	1967		293, 333		No details given.

DATA TABLE 240. THERMAL LINEAR EXPANSION OF THALLIUM MONOBROMIDE TlBr

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 2 (cont.)		CURVE 3 (cont.)‡	
62	-1.187	80	-0.988	551	1.480	180	-0.567
76	-1.166	105	-0.871	601	1.770	200	-0.470
104	-1.071	126	-0.791	658	2.165	220	-0.371
124	-0.951	149	-0.662			240	-0.270
141	-0.863	173	-0.554	CURVE 3‡		260	-0.168
161	-0.767	198	-0.447				
179	-0.662	223	-0.318	25	-1.219	CURVE 4	
191	-0.609	246	-0.195	30	-1.207		
214	-0.466	275	-0.087	40	-1.176	293	0.000
230	-0.386	303	0.049	50	-1.141	333	0.204
246	-0.296	321	0.148	60	-1.103		
264	-0.175	376	0.423	80	-1.023		
293	0.000	417	0.640	100	-0.937		
		468	0.944	120	-0.848		
		486	1.053	140	-0.757		
		526	1.338	160	-0.662		

DATA TABLE 240. COEFFICIENT OF THERMAL LINEAR EXPANSION OF THALLIUM MONOBROMIDE TlBr

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3‡	
25	22.9
30	28.1
40	33.5
50	36.5
60	38.5
80	41.6
100	44.1
120	45.0
140	46.7
160	47.5
180	48.2
200	49.0
220	49.9
240	50.5
260	51.5

* Not shown in figure.
‡ Author's data for coefficient of expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

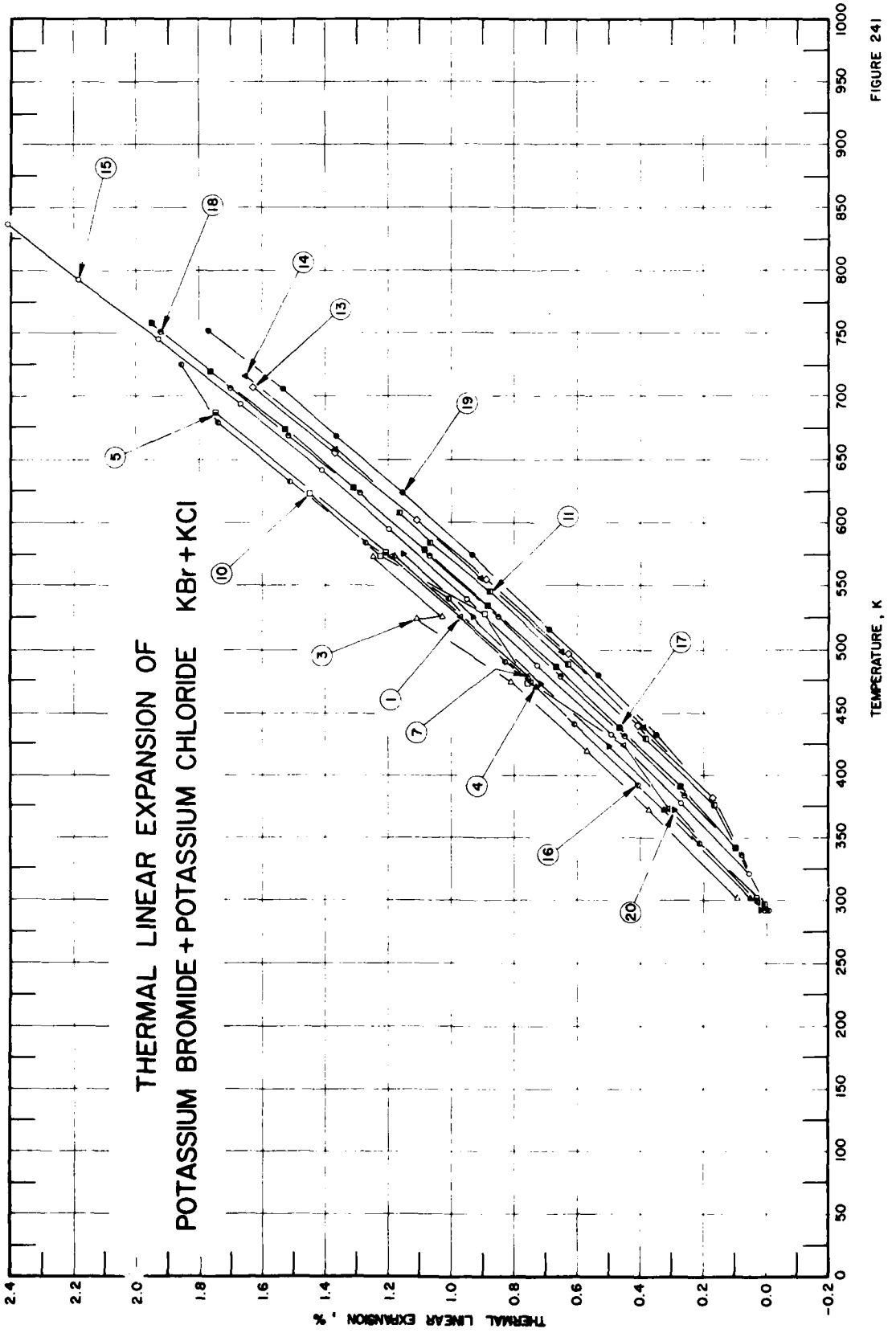

THERMAL LINEAR EXPANSION OF
POTASSIUM BROMIDE + POTASSIUM CHLORIDE KBr + KCl
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1
3
4
5
7
10
11
13
14
15
16
17
18
19
20

FIGURE 241

SPECIFICATION TABLE 241. THERMAL LINEAR EXPANSION OF POTASSIUM BROMIDE + POTASSIUM CHLORIDE KBr + KCl

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) KBr	KCl	Composition (continued), Specifications, and Remarks
1	481	McKinstry, H. A.	1960	X	299-574		61.45	38.54	Solid solution; heated to the annealing temperature ~450 C; allowed to cool slowly with the furnace several times; extrapolated lattice parameters recorded; first run; lattice parameter reported at 299.2 K as 6.44973 Å; 6.44823 Å at 293 K determined by graphical extrapolation.
2*	481	McKinstry, H. A.	1960	X	301-573		61.45	38.54	The above specimen; second run; lattice parameter reported at 301 K as 6.44992 Å; 6.44792 Å at 293 K determined by graphical extrapolation.
3	481	McKinstry, H. A.	1960	X	301-573		13.59	26.4	Solid solution; extrapolated lattice parameters recorded; second run; lattice parameter reported at 301.65 K as 6.48982 Å; 6.48370 Å at 293 K determined by graphical extrapolation.
4	481	McKinstry, H. A.	1960	X	303-469		13.59	26.4	The above specimen; third run; lattice parameter reported at 303.65 K as 6.49021 Å; 6.48714 Å at 293 K determined by graphical extrapolation.
5	481	McKinstry, H. A.	1960	X	301-687		13.59	26.4	The above specimen; fourth run; lattice parameter reported at 301.9 K as 6.48985 Å; 6.48738 Å at 293 K determined by graphical extrapolation.
6*	481	McKinstry, H. A.	1960	X	298-474		51.2	48.79	Solid solution; extrapolated lattice parameters recorded; lattice parameter reported at 298.65 K as 6.48125 Å; 6.41576 Å at 293 K determined by graphical extrapolation.
7	481	McKinstry, H. A.	1960	X	298-573		51.2	48.79	The above specimen; second run; lattice parameter reported at 298.65 K as 6.41709 Å; 6.41587 Å at 293 K determined by graphical extrapolation.
8*	481	McKinstry, H. A.	1960	X	300-472		51.2	48.79	The above specimen; third run; lattice parameter reported at 300.45 K as 6.41753 Å; 6.41555 Å at 293 K determined by graphical extrapolation.
9*	481	McKinstry, H. A.	1960	X	303-425		79.41	20.58	Solid solution; extrapolated lattice parameters recorded; lattice parameter reported at 303.75 K as 6.51195 Å; 6.50914 Å at 293 K determined by graphical extrapolation.
10	481	McKinstry, H. A.	1960	X	300-623		79.41	20.58	The above specimen; another run; lattice parameters recorded; lattice parameter reported at 300.4 K as 6.51149 Å; 6.50973 Å at 293 K determined by graphical extrapolation.
11	481	McKinstry, H. A.	1960	O	296-607		61.45	38.54	Similar to the above specimen; average coefficient of thermal expansion from the previous temperature to the one in question recorded; scattered data points indicated the spread of random error in this particular apparatus; run 1-A; zero-point correction of -0.007% determined by graphical extrapolation.
12*	481	McKinstry, H. A.	1960	O	293-588		61.45	38.54	The above specimen; run 1-B; zero-point correction of -0.001% determined by graphical extrapolation.
13	481	McKinstry, H. A.	1960	O	297-706		61.45	38.54	The above specimen; run 1-C; zero-point correction of -0.007% determined by graphical extrapolation.
14	481	McKinstry, H. A.	1960	O	295-715		61.45	38.54	The above specimen; run 1-D; zero-point correction of -0.004% determined by graphical extrapolation.
15	481	McKinstry, H. A.	1960	O	298-837		61.45	38.54	The above specimen; run 1-E; zerp-point correction of 0.010% determined by graphical extrapolation.
16	481	McKinstry, H. A.	1960	O	292-725		79.41	20.58	Similar to the above specimen; scatter of points lies within a 2% limit of the mean; run 1-E; zero-point correction of 0.003% determined by graphical interpolation.

* Not shown in figure.

SPECIFICATION TABLE 241. THERMAL LINEAR EXPANSION OF POTASSIUM BROMIDE + POTASSIUM CHLORIDE KBr + KCl (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) KBr	KCl	Composition (continued), Specifications, and Remarks
17	481	McKinstry, H. A.	1960	O	292-758		79.41	20.58	The above specimen; run 1-F; zero-point correction of 0.001% determined by graphical interpolation.
18	481	McKinstry, H. A.	1960	O	293-751		79.41	20.58	The above specimen; run 1-G; zero-point correction of -0.009% determined by graphical interpolation.
19	481	McKinstry, H. A.	1960	O	291-752		79.41	20.58	The above specimen; run 1-H; zero-point correction of 0.002% determined by graphical interpolation.
20	481	McKinstry, H. A.	1960	X	298-575		33.92	66.07	Solid solution of 66.07 KCl and 33.92 KBr, alkali halide; lattice parameter reported at 298 K as 6.3703 Å; 6.3691 Å at 293 K determined by graphical extrapolation.

DATA TABLE 241. THERMAL LINEAR EXPANSION OF POTASSIUM BROMIDE + POTASSIUM CHLORIDE KBr + KCl

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
299.20	0.023
373.96	0.314
423.15	0.458
474.90	0.745
525.90	0.974
574.90	1.195
CURVE 2*	
301.2	0.031
370.90	0.301
423.65	0.525
473.40	0.741
525.90	0.973
572.15	1.193
CURVE 3	
301.65	0.094
301.90	0.097*
371.75	0.372
419.90	0.571
421.65	0.583*
474.90	0.808
523.65	1.108
524.40	1.035
573.40	1.255
CURVE 4	
303.65	0.047
373.15	0.325
469.90	0.730
CURVE 5	
301.90	0.038
576.65	1.206
687.15	1.752
CURVE 6*	
298.65	0.020
303.65	0.038
373.15	0.312
373.65	0.314

T	$\Delta L/L_0$
CURVE 6 (cont.)*	
420.40	0.511
420.40	0.512
474.15	0.744
CURVE 7	
298.65	0.019*
300.85	0.025*
477.15	0.759
524.90	0.979*
573.15	1.182
CURVE 8*	
300.45	0.030
373.65	0.341
472.90	0.751
CURVE 9*	
303.65	0.043
374.40	0.330
425.90	0.550
CURVE 10	
300.40	0.027*
304.15	0.041*
473.40	0.752
527.65	0.999
574.65	1.221
623.75	1.451
CURVE 11	
296.6	0.007
375.1	0.162
429.3	0.381
487.0	0.625
545.8	0.879
584.8	1.067
607.1	1.167
CURVE 12*	
293.6	0.001

T	$\Delta L/L_0$
CURVE 12 (cont.)*	
372.1	0.157
428.1	0.383
485.6	0.627
543.4	0.880
588.3	1.083
CURVE 13	
297.1	0.007*
382.0	0.173
439.8	0.402
495.2	0.627
555.6	0.890
601.2	1.106
655.1	1.369
706.5	1.629
CURVE 14	
295.4	0.004*
381.9	0.172*
438.6	0.397
497.7	0.646
555.6	0.901
601.6	1.111*
657.0	1.369
715.5	1.658
CURVE 15	
298.3	0.010*
321.4	0.054
377.0	0.272
431.5	0.496
486.0	0.725
540.3	0.956
595.1	1.200
641.6	1.417
694.4	1.671
745.0	1.930
794.0	2.185
837.2	2.410
CURVE 16	
292.2	-0.003

T	$\Delta L/L_0$
CURVE 16 (cont.)	
345.6	0.210
392.2	0.405
440.4	0.614
489.4	0.832
539.4	1.063
584.3	1.276
631.9	1.508
679.0	1.740
725.4	1.855
CURVE 17	
292.1	-0.001*
342.4	0.090
390.0	0.273
437.7	0.467
485.5	0.668
535.5	0.885
579.7	1.085
626.8	1.306
674.0	1.533
720.3	1.763
758.0	1.950
CURVE 18	
293.5	0.000
335.8	0.078
383.2	0.260
430.3	0.449
478.9	0.650
525.2	0.850
574.4	1.070
622.1	1.292
669.7	1.520
706.5	1.701
750.7	1.922
CURVE 19	
291.6	-0.002*
383.8	0.166*
431.6	0.348
479.1	0.538
515.3	0.688
574.3	0.939

T	$\Delta L/L_0$
CURVE 19 (cont.)	
623.6	1.158
668.2	1.361
705.0	1.539
711.0	1.568*
751.9	1.772
CURVE 20	
298.20	0.019
372.70	0.294
374.20	0.303*
422.45	0.500
472.70	0.713
473.95	0.704*
525.45	0.937
525.70	0.937*
572.70	1.15
575.45	1.15

* Not shown in figure.

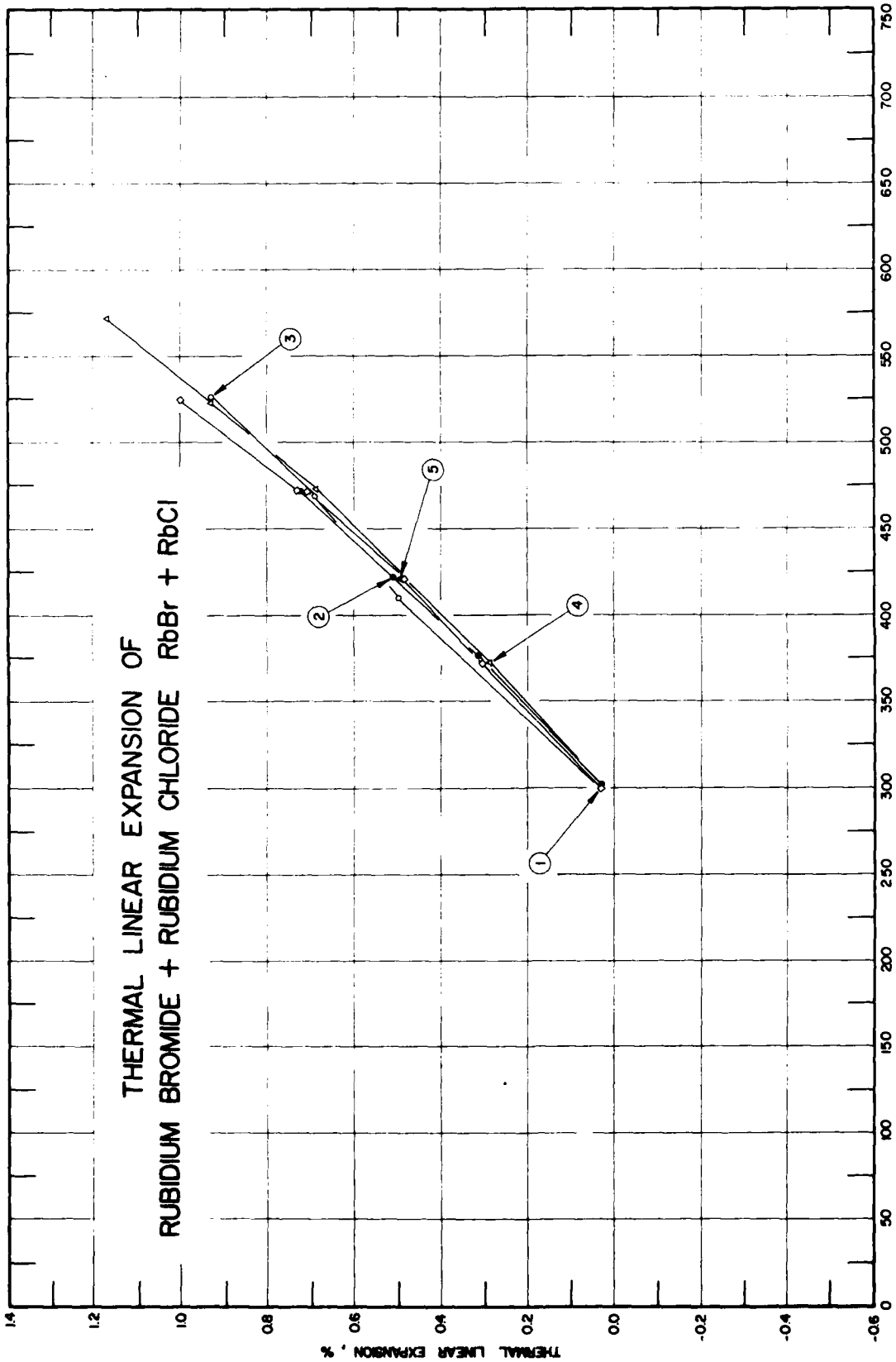

THERMAL LINEAR EXPANSION OF
RUBIDIUM BROMIDE + RUBIDIUM CHLORIDE RbBr + RbCl
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
1
2
3
4
5

FIGURE 242

SPECIFICATION TABLE 242. THERMAL LINEAR EXPANSION OF RUBIDIUM BROMIDE + RUBIDIUM CHLORIDE RbBr + RbCl

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) RbBr	RbCl	Composition (continued), Specifications, and Remarks
1		McKinstry, H.A.	1960	X	300-526		80.9	19.0	Solid solution of RbBr and RbCl, <2% potassium; rubidium bromide prepared from a chemically pure $RbCO_3$ and chemically pure hydrobromic acid; rubidium chloride prepared from a chemically pure $RbCO_3$ and chemically pure hydrochloric acid; lattice parameter reported at 300.4 K as 6.81356 Å; 6.81164 Å at 293 K determined by graphical extrapolation.
2		McKinstry, H.A.	1960	X	301-474		57.79	42.2	Solid solution of RbBr and RbCl; lattice parameter reported at 301.9 K as 6.72482 Å; 6.72253 Å at 293 K determined by graphical extrapolation.
3		McKinstry, H.A.	1960	X	299-527		57.79	42.2	The above specimen; second run; lattice parameter reported at 299.65 K as 6.72414 Å; 6.72239 Å at 293 K determined by graphical extrapolation.
4		McKinstry, H.A.	1960	X	300-573		31.32	68.67	Solid solution of 68.67 RbCl and 31.32 RbBr; respectively prepared from chemically pure $RbCO_3$ plus hydrochloric acid and pure $RbCO_3$ plus hydrobromic acid; data obtained by the use of four reflections $K\alpha_1$ and $K\alpha_2$; lattice parameter reported at 300 K as 6.6651 Å; 6.6632 Å at 293 K determined by graphical extrapolation.
5		McKinstry, H.A.	1960	X	300-524				The above specimen; data obtained using four reflections $K\alpha_1$ and $K\alpha_2$ plus two low order reflections; lattice parameter reported at 300 K as 6.6651 Å; 6.66326 Å at 293 K determined by graphical extrapolation.

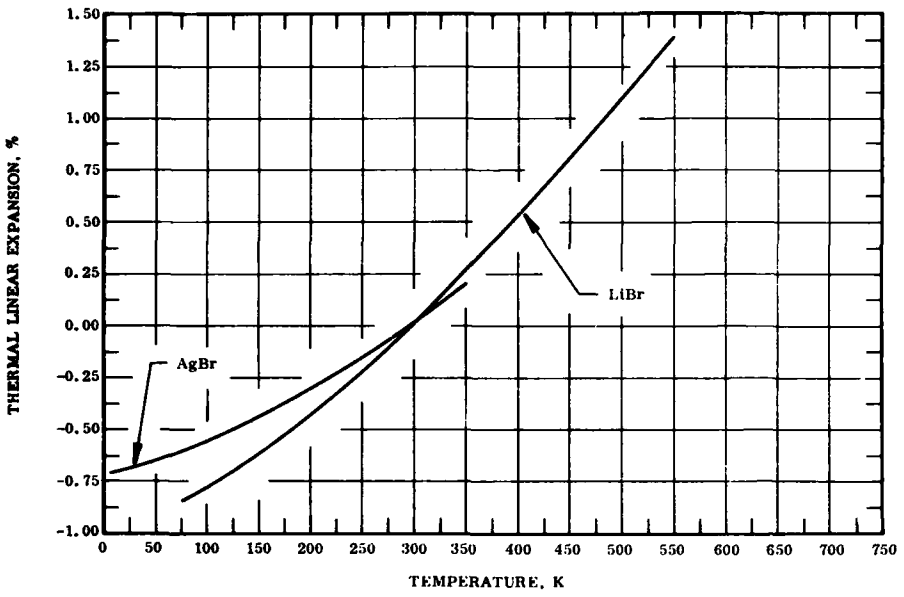
DATA TABLE 242. THERMAL LINEAR EXPANSION OF RUBIDIUM BROMIDE + RUBIDIUM CHLORIDE RbBr + RbCl

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
300.40	0.028
372.40	0.303
421.90	0.481
472.90	0.713
472.90	0.726
525.65	1.00
CURVE 2	
301.90	0.034
374.40	0.307*
376.40	0.316
423.65	0.512
473.90	0.723
CURVE 3	
299.65	0.026*
410.40	0.500
468.15	0.692
526.40	0.926
CURVE 4	
300.45	0.002
372.95	0.298
472.95	0.499
473.70	0.694
524.95	0.930
573.45	1.17
CURVE 5	
300.45	0.028*
372.95	0.298*
422.95	0.491
473.70	0.693*
524.95	0.927*

* Not shown in figure.

FIGURE AND TABLE NO. 243R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF MISCELLANEOUS BROMIDES AND BROMIDE MIXTURES



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

LiBr			AgBr		
T	$\Delta L/L_0$	α	T	$\Delta L/L_0$	α
75	-0.851	24.0	5	-0.710	5.0
100	-0.797	28.6	10	-0.709	6.4
150	-0.629	37.7	25	-0.697	10.2
200	-0.427	42.7	50	-0.668	15.6
250	-0.202	46.4	75	-0.622	19.8
293	0.000	48.6	100	-0.563	23.4
300	0.035	48.9	150	-0.437	26.8
350	0.285	50.8	200	-0.296	29.7
400	0.538	52.4	250	-0.141	32.0
450	0.802	54.8	293	0.000	33.6
500	1.085	58.5	300	0.024	33.8
550	1.393	63.1	325	0.109	34.4
			350	0.196	35.0

REMARKS

LiBr: The recommended values are based on the most recent measurements. These values are considered accurate to within ± 5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -1.790 + 8.033 \times 10^{-3}\ T - 9.402 \times 10^{-6}\ T^2 + 9.670 \times 10^{-9}\ T^3 \qquad (293\text{-}550\ K)$$

The tabulated values for the coefficient of thermal linear expansion are based on the experimental data and are considered accurate to about ± 10%.

AgBr: The recommended values are considered accurate to within ± 5% and can be represented approximately by the following equation:

$$\Delta L/L_0 = -0.756 + 1.486 \times 10^{-3}\ T + 4.807 \times 10^{-6}\ T^2 - 3.674 \times 10^{-9}\ T^3 \qquad (100\text{-}350\ K)$$

The tabulated values for the coefficient of thermal linear expansion are derived by differentiating the above and more complicated equations which are used to fit the low temperature data. These values are considered accurate to about ± 10%.

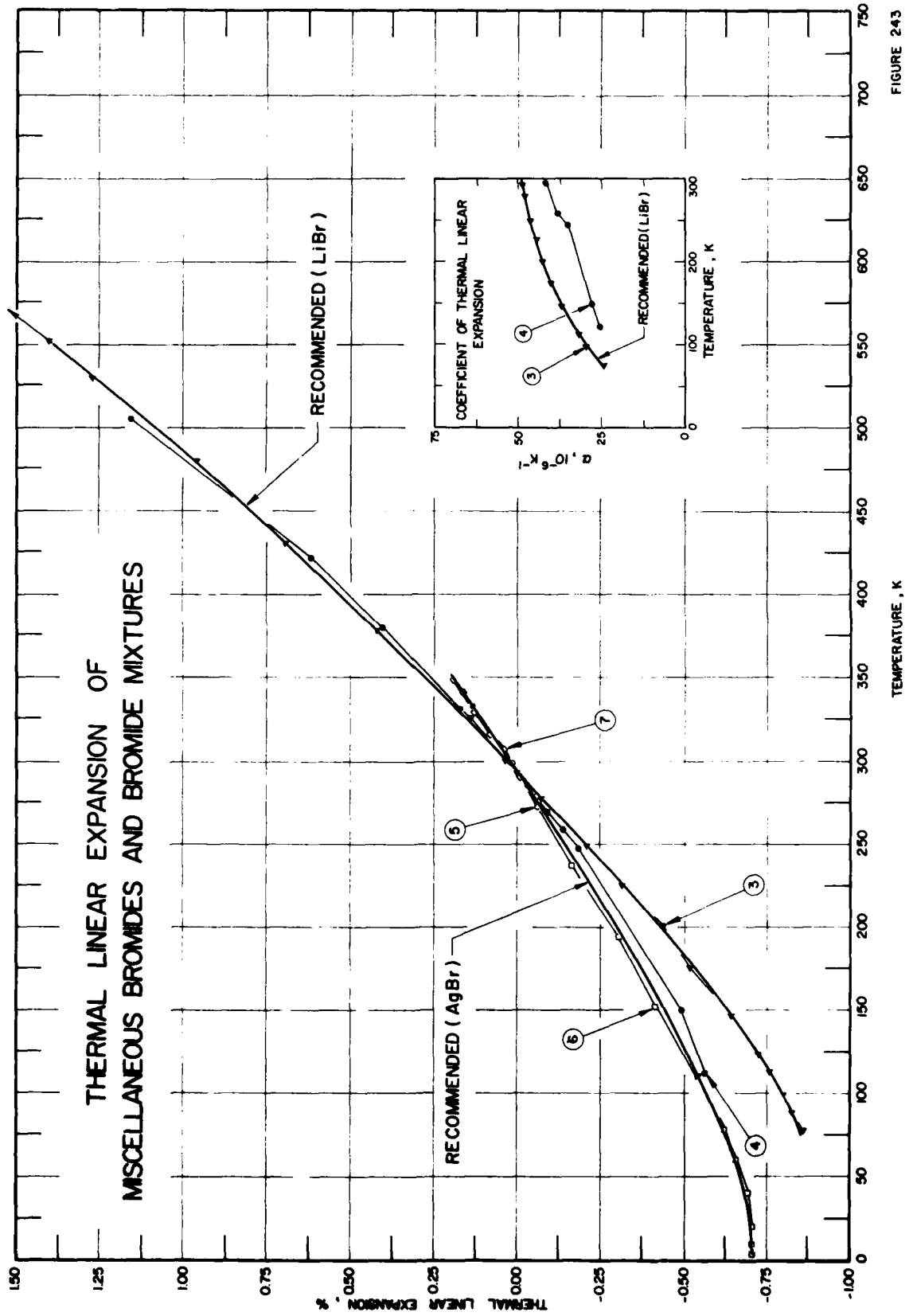

THERMAL LINEAR EXPANSION OF
MISCELLANEOUS BROMIDES AND BROMIDE MIXTURES
RECOMMENDED (LiBr)
RECOMMENDED (AgBr)
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED(LiBr)
α , 10⁻⁶ K⁻¹
TEMPERATURE , K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K

FIGURE 243

SPECIFICATION TABLE 243. THERMAL LINEAR EXPANSION OF MISCELLANEOUS BROMIDES AND BROMIDE MIXTURES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	160	Schaake, H.F.	1969	X	4-299	CuBr	Copper bromide; specimen from Fisher, C-450; ground to < 325 mesh, 10% iridium added for calibration, pressed into copper sample holder, annealed 2 hr at 473 K.
2*	632	Bridgman, P.W.	1932		303, 348	CuBr	Copper bromide; specimen pressed into a 9.525 mm diameter by 9.525-12.70 mm long cylinder; used lever piezometer method.
3	626	Rapp, J.E. and Merchant, H.D.	1972	L	76-580	LiBr	Lithium bromide; crystal orientation < 1, 0, 0 >; dimensions were 5 x 5 x 50 mm; smoothed data.
4	663	Von Trost, K.F.	1962		122-507	LiBr	Lithium bromide; no details given.
5	148	Ballard, S.S. and Browder, J.S.	1966	I	273-332	AgBr	Silver bromide; single crystal, produced by Harshaw Co., density 6.47 g/cc, at 3.3 μ refractive index 2.23, long wavelength transmission limit 35 μ.
6	160	Schaake, H.F.	1969	X	4-299	AgBr	Silver bromide; from Fisher, S-172; powder ground to < 325 mesh, 10% iridium added for calibration, pressed into copper holder, annealed 2 hr at 473 K; lattice parameter reported at 299 K as 5.7743 Å; 5.7732 Å at 293 K determined by graphical interpolation.
7	630, 631	Ballard, S.S. and Browder, J.S.	1967	I	278-348	AgBr	Silver bromide; single crystal specimen.
8*	481	McKinstry, H.A.	1960	X	300-473	KBr + RbBr	Potassium bromide + rubidium bromide; 74.43 KBr and 25.56 RbBr; solid solution of KBr and RbBr; proper heat treatment hard to obtain; lattice parameter reported at 200.65 K as 6.68307 Å; 6.62551 Å at 293 K determined by graphical extrapolation.
9*	481	McKinstry, H.A.	1960	X	295-575	KBr + RbBr	Potassium bromide + rubidium bromide; 74.43 KBr and 25.56 RbBr; the above specimen; second run; lattice parameter reported at 295.15 K as 6.68147 Å; 6.62187 Å at 293 K determined by graphical extrapolation.
10*	481	McKinstry, H.A.	1960	X	299-573	KBr + RbBr	Potassium bromide + rubidium bromide; 80.66 KBr and 19.33 RbBr; solid solutions of RbBr and KBr; the composition prepared from a chemically pure $RbCO_3$ and chemically pure hydro-bromic acid; lattice parameters extrapolated to reduce systematic error; lattice parameter reported at 299.4 K as 6.81795 Å; 6.81619 Å at 293 K determined by graphical interpolation.
11*	481	McKinstry, H.A.	1960	X	301-415	KBr + RbBr	Potassium bromide + rubidium bromide; 58.17 KBr and 41.82 RbBr; solid solution; proper heat treatment hard to obtain; extrapolated lattice parameters recorded; lattice parameter reported at 301.90 K as 6.75861 Å; 6.64563 Å at 293 K determined by graphical extrapolation.

* No figure given.

DATA TABLE 243. THERMAL LINEAR EXPANSION OF MISCELLANEOUS BROMIDES AND BROMIDE MIXTURES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
4.2	-0.237
20	-0.242
40	-0.251
60	-0.249
77.4	-0.247
99	-0.239
120	-0.219
140	-0.200
194.5	-0.137
240	-0.073
299	0.008
CURVE 2*	
303	0.021
348	0.114
CURVE 3‡	
76	-0.865
87	-0.837

T	$\Delta L/L_0$
CURVE 3 (cont.)‡	
99	-0.804
113	-0.761
123	-0.728
146	-0.647
175	-0.534
200	-0.430
225	-0.320
248	-0.215
277	-0.078
293	0.000
300	0.034
325	0.158
377	0.423
428	0.691
479	0.969
531	1.270
554	1.411
580	1.579

T	$\Delta L/L_0$
CURVE 4‡	
122	-0.565
148	-0.495
245	-0.188
258	-0.140
269	-0.097
293	0.000
330	0.163
379	0.404
422	0.639
507	1.165
CURVE 5	
273	-0.069
298	0.017
332	0.139
CURVE 6	
4.2	-0.718
10	-0.717

T	$\Delta L/L_0$
CURVE 6 (cont.)	
20	-0.717
40	-0.692
60	-0.658
77.4	-0.633
110	-0.540
151	-0.417
194.5	-0.306
237	-0.162
273	-0.055
299	0.017
CURVE 7‡	
278	-0.052
281	-0.041
283	-0.034
285	-0.027
287	-0.021
288	-0.017
290	-0.008
293	-0.001

T	$\Delta L/L_0$
CURVE 7 (cont.)‡	
294	0.004
306	0.046
315	0.076
320	0.094
329	0.125
336	0.151
340	0.165
348	0.193
CURVE 8*	
300.65	0.031
373.15	0.318
422.15	0.530
473.90	0.744
CURVE 9*	
295.15	0.009
298.90	0.024
470.90	0.724
575.40	1.21

T	$\Delta L/L_0$
CURVE 10*	
299.40	0.026
374.40	0.325
376.65	0.332
423.65	0.524
472.90	0.732
524.40	0.956
572.40	1.18
CURVE 11*	
301.90	0.017
373.15	0.153
424.65	0.512
475.90	0.578

DATA TABLE 243. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS BROMIDES AND BROMIDE MIXTURES

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3*,‡	
76	24.1
87	26.2
99	29.4
113	31.9
123	33.6
146	37.3
175	40.5
200	42.8
225	44.8
248	46.7
277	48.2
293	48.8

T	α
CURVE 3 (cont.)*,‡	
300	49.2
325	50.1
377	51.6
428	53.4
479	55.8
531	59.9
554	63.0
580	66.1
CURVE 4*,‡	
122	25.5

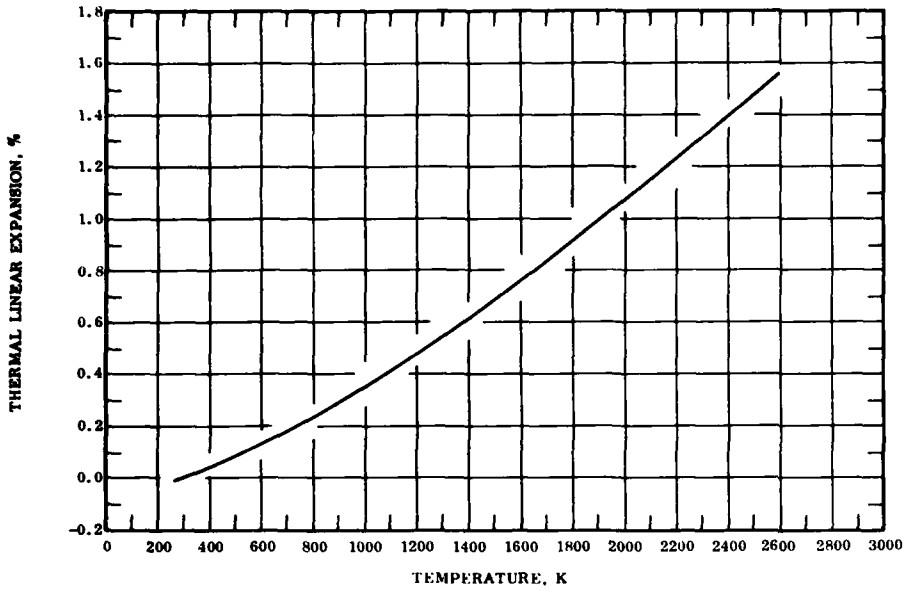
T	α
CURVE 4 (cont.)*,‡	
148	28.0
245	35.4
258	38.2
269	39.3
293	41.9
330	46.4
379	51.9
422	57.3
507	66.5

T	α
CURVE 7*,‡	
278	34.67
281	34.66
283	34.74
285	34.81
287	34.76
288	34.74
290	34.76
293	34.73
294	34.76
306	34.73
315	34.73
320	34.62

T	α
CURVE 7 (cont.)*,‡	
329	34.59
336	34.64
340	34.64
348	34.64

* Not shown in figure.
‡ Author's data for coefficient of expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 244R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF TETRABORON CARBIDE B_4C



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	4.8
300	0.003	4.8
400	0.048	4.8
500	0.094	4.8
600	0.142	4.9
700	0.193	5.0
800	0.247	5.2
900	0.302	5.5
1000	0.360	5.8
1100	0.420	6.1
1200	0.483	6.3
1300	0.547	6.6
1400	0.614	6.8
1500	0.683	7.0
1600	0.753	7.3
1700	0.826	7.5
1800	0.901	7.7
1900	0.978	7.9
2000	1.057	8.0
2100	1.138	8.2
2200	1.220	8.3
2300	1.305	8.5
2400	1.391	8.6
2500	1.479	8.8
2600	1.569	8.9

REMARKS

The recommended values are based on the data for samples with a density of 2.5 g cm^{-3}. These values are considered accurate to within ± 5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.114 + 3.523 \times 10^{-4}\, T + 1.266 \times 10^{-7}\, T^2 - 5.085 \times 10^{-12}\, T^3$$

The tabulated values for the coefficient of thermal expansion are calculated primarily by differentiating the above equations and are considered accurate to about ± 10%.

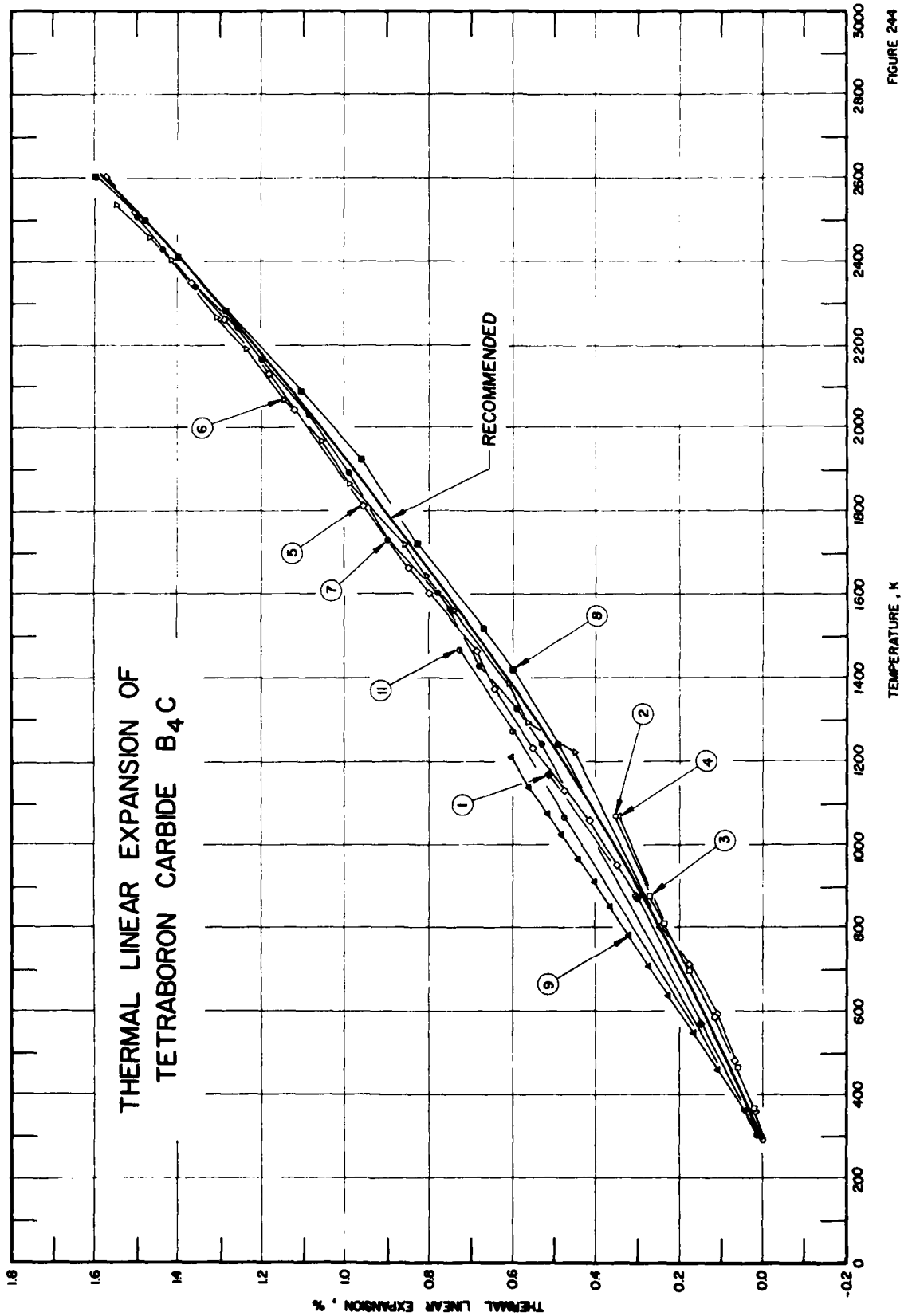

THERMAL LINEAR EXPANSION OF
TETRABORON CARBIDE B_4C
RECOMMENDED
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
1
2
3
4
5
6
7
8
9
11

FIGURE 244

SPECIFICATION TABLE 244. THERMAL LINEAR EXPANSION OF TETRABORON CARBIDE B_4C

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	298-1173		Specimen with cross section 0.5 x 0.5 in. and 7 in. long; hot molded; the ends sawed at rake and to a point.
2	69	Finlay, G.R.	1952		293,1073		Rhombohedral structure specimen; density 2.50 g cm^{-3}; m.p. 2723 K.
3	145	Gangler, J.J.	1950	I	297-877		Three pyramids 4 to 5 mm in height constituted a single specimen; specimen hot pressed; expansion obtained was an average of expansion of all three pyramids; data from smoothed curve; zero-point correction of 0.006% determined by graphical extrapolation.
4	434	Finlay, G.R.	1957		293,1073		78.3 B; concentrated form of boron; density 2.50 g cm^{-3}; m.p. 2723 K.
5	64	Hedge, J.C., Kostenko, C., and Lang, J.I.	1963		299-2604		75.97 B, 21.18 C, 0.40 Si, 0.27 Fe, 0.07 B_2O_3, and 0.015 Al_2O_3; Carborundum Co.; dimensions 0.5 in. diameter by 6 in. long; hot pressed and fired at 2444 K; density 2.50 g cm^{-3}; measured in argon atmosphere with heating rate of approximately 3 K per min.; reported error 2%.
6	70	Engberg, C.J. and Zehms, E.H.	1958	T	301-2541	AZ-1	Specimen hot pressed; density 2.50 g cm^{-3}; expansion measured in argon atmosphere.
7	70	Engberg, C.J. and Zehms, E.H.	1958	T	2518-306	AZ-1	The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.060% determined by graphical extrapolation.
8	70	Engberg, C.J. and Zehms, E.H.	1958	T	301-2601	AZ-2	Similar to the above specimen; expansion measured in argon atmosphere with increasing temperature.
9	676	Yakel, H.L.	1973	X	285-1213		78 B, 22 C, cylindrical specimen 0.5 mm diameter in thin walled quartz capillary tube; from Norton Chemical Co., Worcester, Mass.
10	676	Yakel, H.L.	1973	X	285-1218		95 B, 5 C, cylindrical specimen 0.5 mm diameter in thin walled quartz capillary tube; prepared by J. P. Deluca at Oak Ridge National Labs.
11	677	Neshpor, V.S., Nikitin, V.P., and Rabotnov, V.V.	1970	O	1073-1473		78.28 B, 21.72 C in shapes of 0.8-1.2 mm hemispheres.

DATA TABLE 244. THERMAL LINEAR EXPANSION OF TETRABORON CARBIDE B_4C

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.003*
573	0.146
873	0.307
1173	0.510
CURVE 2	
293	0.00
1073	0.35
CURVE 3	
297	0.006*
366	0.025
478	0.063
589	0.119
700	0.175
810	0.237
877	0.273
CURVE 4	
293	0.00
1073	0.34
CURVE 5	
299	0.002
361	0.023
484	0.069
595	0.125
715	0.179
802	0.247
873	0.306
954	0.350
1061	0.414
1135	0.473
1234	0.549
1376	0.643
1467	0.690
1602	0.802
1666	0.851
1819	0.958
2048	1.126
2133	1.183
2263	1.294
CURVE 5 (cont.)	
2353	1.369
2523	1.501
2604	1.572
CURVE 6	
301	0.003*
1221	0.45
1297	0.56
1389	0.61
1565	0.74
1649	0.81
1725	0.86
1865	0.99
1969	1.06
2073	1.15
2193	1.24
2269	1.31
2405	1.42
2461	1.47
2541	1.55
CURVE 7	
2518	1.485
2437	1.433
2343	1.348
2242	1.253
2168	1.191
2039	1.084
1894	0.976
1739	0.886
1604	0.762
1569	0.741
1434	0.665
1331	0.575
1245	0.521
306	0.006
CURVE 8	
301	0.003*
1241	0.49
1421	0.60
1521	0.67
1725	0.83
CURVE 8 (cont.)	
1925	0.96
2093	1.11
2285	1.29
2413	1.40
2505	1.48
2601	1.60
CURVE 9‡	
285	-0.005
364	0.047
461	0.110
550	0.169
643	0.230
716	0.278
782	0.321
853	0.368
911	0.406
966	0.442
1028	0.483
1079	0.516
1142	0.558
1213	0.604
CURVE 10‡	
285	-0.005
553	0.172
683	0.258
792	0.329
895	0.398
1038	0.492
1116	0.543
1173	0.581
1218	0.611
CURVE 11‡	
1073	0.479
1273	0.602
1473	0.730

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 244. COEFFICIENT OF THERMAL LINEAR EXPANSION OF TETRABORON CARBIDE B_4C

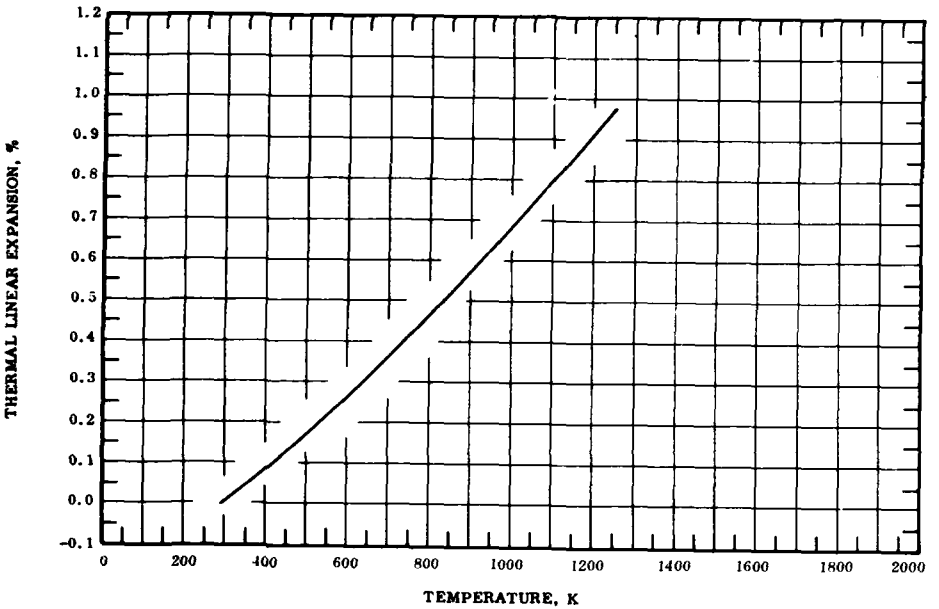
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 9*,‡	
285	6.5704
364	6.5704
461	6.5698
550	6.5699
643	6.5703
716	6.5698
782	6.5705
853	6.5692
911	6.5708
966	6.5694
1028	6.5700
1079	6.5692
1142	6.5697
1213	6.5693
CURVE 10*,‡	
285	6.6024
553	6.6029
683	6.6040
792	6.6034
895	6.6030
1038	6.6032
1116	6.6022
1173	6.6020
1218	6.6010
CURVE 11*,‡	
1073	5.96
1273	6.33
1473	6.43

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta l/l_0 = 0$.

FIGURE AND TABLE NO. 245R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF TRICHROMIUM DICARBIDE Cr_3C_2



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	7.8
300	0.006	7.9
400	0.088	8.4
500	0.174	8.9
600	0.266	9.4
700	0.362	9.9
800	0.463	10.4
900	0.569	10.8
1000	0.679	11.3
1100	0.794	11.7
1200	0.913	12.1
1250	0.975	12.4

REMARKS

The recommended values are for hot-pressed samples. These values are considered accurate within ± 5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.208 + 6.333 \times 10^{-4}\ T + 2.679 \times 10^{-7}\ T^2 - 1.435 \times 10^{-11}\ T^3$$

The tabulated values of the coefficient of thermal expansion are derived primarily by differentiating the above equation and are considered accurate to about ± 7%.

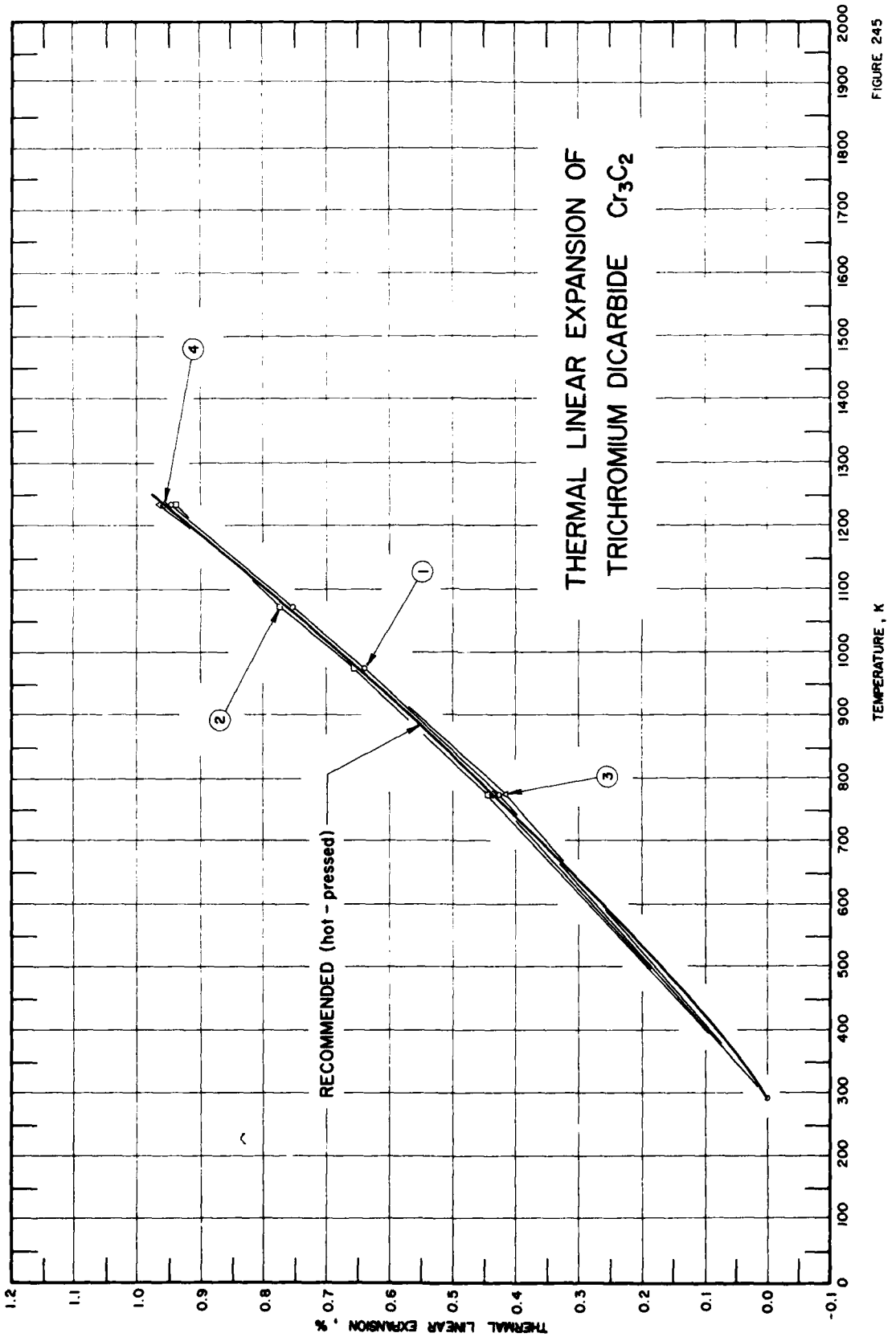

THERMAL LINEAR EXPANSION OF
TRICHROMIUM DICARBIDE Cr_3C_2
RECOMMENDED (hot - pressed)
1
2
3
4
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 245

SPECIFICATION TABLE 245. THERMAL LINEAR EXPANSION OF TRICHROMIUM DICARBIDE Cr_3C_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	12	Graham, S. A.	1950	T	293-1233		Commercial powder ball milled to ~5 μ, hot pressed into bar and ground to 1.3 x 0.14 in. square; expansion measured in argon atmosphere on run No. 1; reported error < 5.0%.
2	12	Graham, S. A.	1950	T	1233-293		The above specimen; expansion measured with decreasing temperature.
3	12	Graham, S. A.	1950	T	293-1233		The above specimen; expansion measured with increasing temperature on run No. 2.
4	12	Graham, S. A.	1950	T	1233-293		The above specimen; expansion measured with decreasing temperature.

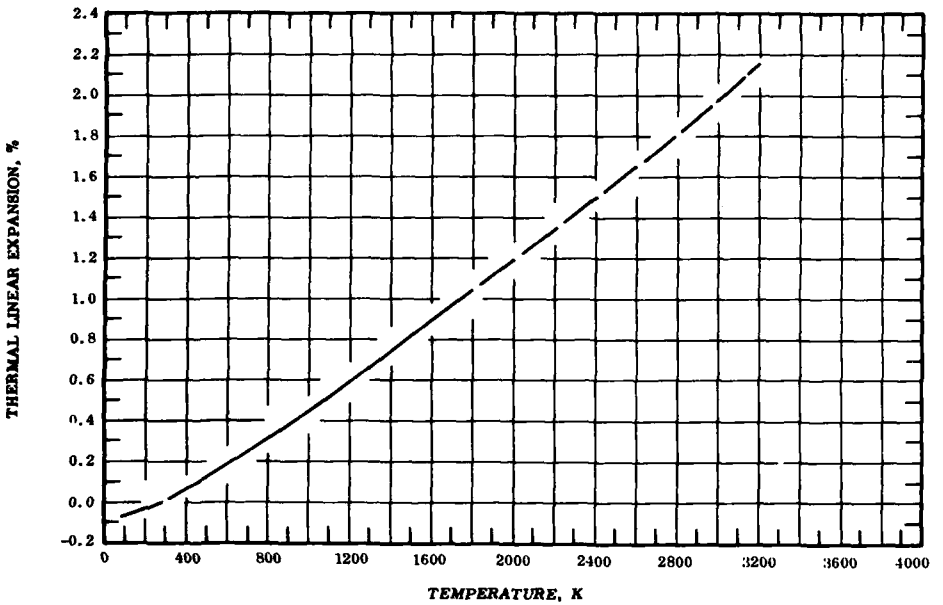
DATA TABLE 245. THERMAL LINEAR EXPANSION OF TRICHROMIUM DICARBIDE Cr_3C_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.00
773	0.43
973	0.64
1073	0.76
1233	0.95
CURVE 2	
1233	0.94
1073	0.78
973	0.66
773	0.45
293	0.00*
CURVE 3	
293	0.00*
773	0.42
973	0.64*
1073	0.76*
1233	0.97
CURVE 4	
1233	0.97
1073	0.77*
973	0.65*
773	0.44
293	0.00*

* Not shown in figure.

FIGURE AND TABLE NO. 246R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF HAFNIUM CARBIDE HfC



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
80	-0.067†	1.3
100	-0.064†	1.7
200	-0.038†	3.4
293	0.000	4.9
300	0.004	5.0
400	0.066	6.1
500	0.129	6.5
600	0.194	6.7
700	0.260	6.8
800	0.328	6.9
900	0.396	6.9
1000	0.466	7.0
1200	0.607	7.2
1400	0.751	7.3
1600	0.897	7.3
1800	1.043	7.3
2000	1.188†	7.4
2200	1.331†	7.5
2400	1.482†	7.7
2600	1.640†	8.0
2800	1.804†	8.3
3000	1.976†	8.8
3200	2.155†	9.2

† Provisional values.

REMARKS

The recommended values are for pure sample and are based on the closely agreeing most recent measurements (1, 2, 3, 7 and 9). No weight was given in the analysis to curves 5 and 6. The recommended values are considered accurate to within ± 5% at temperatures below 1800 K and to within ± 10% above 1800 K. These values are represented approximately by the following equations:

$$\Delta L/L_0 = -0.170 + 5.521 \times 10^{-4}\, T + 1.041 \times 10^{-7}\, T^2 - 2.015 \times 10^{-11} \qquad (293\text{-}2000\ K)$$

$$\Delta L/L_0 = 7.367 \times 10^{-2} + 4.217 \times 10^{-4}\, T + 6.072 \times 10^{-8}\, T^2 + 3.374 \times 10^{-12}\, T^3 \qquad (2000\text{-}3200\ K)$$

The tabulated values of the coefficient of thermal expansion are based on the experimental data and the values obtained by differentiating the above equations. These values are considered accurate to about ± 7%.

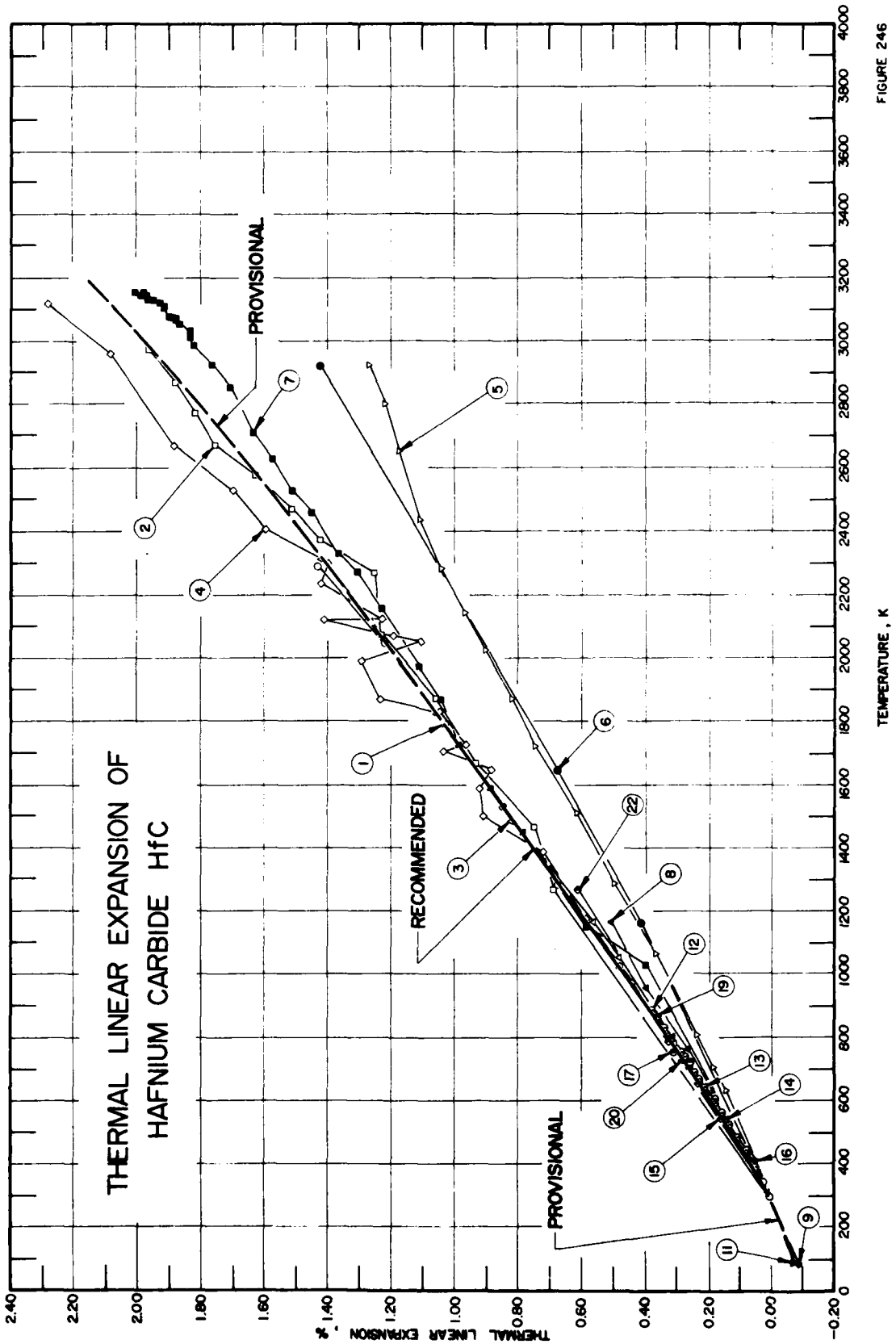

THERMAL LINEAR EXPANSION OF
HAFNIUM CARBIDE HfC
PROVISIONAL
RECOMMENDED
PROVISIONAL
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
1
2
3
4
5
6
7
8
9
11
12
13
14
15
16
17
19
20
22

FIGURE 246

SPECIFICATION TABLE 246. THERMAL LINEAR EXPANSION OF HAFNIUM CARBIDE HfC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	438	Houska, C.R.	1963	X	298-2299	$HfC_{0.95}$	97.29 HfC, 2.04 C, 0.55 Zr, 0.08 N, 0.06 O, and 0.02 Ti; specimen made by reacting HfO_2 with carbon at about 2753 K for 1 hr, cold pressed, using camphor lubricant at 14 000 psi, sintered in vacuum at 2173 K for 1 hr; data obtained using CuKα radiation, from (511/333) and (440); reported error < 2%; zero-point correction of 0.003% determined by graphical extrapolation.
2	422	Richardson, J.H.	1965	X	300-2978		96.6 Hf, 3.2 Zr, 0.092 O, 0.086 Mg, 0.039 Fe, 0.035 Ni, 0.015 Cr, 0.011 Cl, and 0.002 Ti; prepared by vacuum arc casting; slurry made of 0.1 g of powdered carbide with 0.5 ml of binder solution (Duco cement and acetone 1:20 by volume); uniform layer of slurry applied to central portion of major surface on graphite heating element, and allowed to dry for 5 min.; CuKβ radiation, and (111) reflections used; zero-point correction of 0.005% determined by graphical extrapolation.
3	423	Brizes, W.F.	1968	T	783-2320		High purity Hf rod inserted into graphite mold; diffusion annealed at about 473 K below carbide-carbon eutectic temperature; expansion measured in 15 μ of He atmosphere.
4	426	Paderno, Yu.B.	1965	T	293-3121		98.67 pure, 0.58 free carbon; 15 to 18 mm long, 8 mm diameter; hot pressed specimen; expansion measured under 10^{-2} mm Hg pressure atmosphere.
5	318	Neel, D.S., Pears, C.D., and Oglesby, S., Jr.	1962	L	293-2927		Before exposure 93.8 Hf, 5.85 C, 1.0 N, elements found by semi-quantitative emission spectrography 0.2 Al and 0.3 Ti; after exposure 93.9 Hf, 5.73 C, and 0.3 N; initial length 3.0040 in., final length 3.0015 in.; obtained from Carborundum Co.; hot pressed and final near 3590 K; run SRI-E28; density in g cm^{-3} at 298 K before exposure 11.2 by ASTM method B311-58, 11.5 by wax coating specimen, 12.0 by immersion in xylene, after exposure 11.2 by ASTM method, 11.1 by wax coating specimen and 11.8 by immersion in xylene; expansion measured in helium atmosphere; reported error 2%.
6	318	Neel, D.S., et al.	1962	L	2928-293		The above specimen; expansion measured with decreasing temperature.
7	318	Neel, D.S., et al.	1962	L	293-3155		Second exposure of above specimen; exposure used to heat soak new dilatometer parts; Run SRI-E32.
8	439	Nowotny, H.	1961		293-1163		Specimen of almost stoichiometric composition.
9	433	Krikorian, N.H., Wallace, T.C., and Anderson, J.L.	1963	X	83,299	$HfC_{0.97}$	0.2 deficiency of carbon; specimen prepared from 99.98 pure Hf and spectroscopic grade graphite, reacted 1 to 2 hr at 2473 K in vacuum of 10^{-5} to 10^{-6} Torr; lattice parameter reported at 299 K is 4.6395 Å; 4.6394 Å at 293 K determined by graphical interpolation.
10*	433	Krikorian, N.H., et al.	1963	X	83,299	$HfC_{0.95}$	Similar to the above specimen except 5.0 carbon deficient; lattice parameter reported at 299 K is 4.6381 Å; 4.6380 Å at 293 K determined by graphical interpolation.
11	433	Krikorian, N.H., et al.	1963	X	83,299	$HfC_{0.89}$	Similar to the above specimen except 11.0 carbon deficient; lattice parameter reported at 299 K is 4.6382 Å; 4.6381 Å at 293 K determined by graphical interpolation.
12	440	Grisaffe, S.J.	1960	I	293-889	Test I	95.4 pure, 3.45 Zr, 0.72 B, 0.39 Ti, 0.03 free C; hot pressed specimen ground to cone 0.51 cm high; expansion measured with heating rate 4.5 K per min.; density 11.8 g cm^{-3}; reported error < 1.0%.

* Not shown in figure.

SPECIFICATION TABLE 246. THERMAL LINEAR EXPANSION OF HAFNIUM CARBIDE HfC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
13	440	Grisaffe, S.J.	1960	I	719-296	Test I	The above specimen; expansion measured with decreasing temperature.
14	440	Grisaffe, S.J.	1960	I	301-879	Test IA	The above specimen; expansion measured with increasing temperature on second thermal cycle.
15	440	Grisaffe, S.J.	1960	I	893-492	Test IA	The above specimen; expansion measured with decreasing temperature.
16	440	Grisaffe, S.J.	1960	I	351-827	Test II	Similar to the above specimen; expansion measured with increasing temperature; density 12.0 g cm^{-3}.
17	440	Grisaffe, S.J.	1960	I	795-487	Test II	The above specimen; expansion measured with decreasing temperature.
18*	440	Grisaffe, S.J.	1960	I	298-877	Test IIA	The above specimen; expansion measured on second thermal cycle with increasing temperature.
19	440	Grisaffe, S.J.	1960	I	863-564	Test IIA	The above specimen; expansion measured with decreasing temperature.
20	440	Grisaffe, S.J.	1960	I	342-836	Test III	Similar to the above specimen; density 11.6 g cm^{-3}; expansion measured with increasing temperature.
21*	440	Grisaffe, S.J.	1960	I	797-551	Test III	The above specimen; expansion measured with decreasing temperature.
22	432	Miccioli, B.R. and Julien, H.P.	1965	T	300, 1273		Hot pressed specimen; density 11.90 g cm^{-3}; expansion measured parallel to pressing direction.
23*	443	Bernstein, H.	1964		1073, 1773		Powder specimen sifted through 200 mesh screen and deposited as a thin acetone slurry directly on the tantalum heater strips; (heater strips annealed at 1773 K for several hr prior to use); expansion measured under pressure of 1-2 x 10^{-5} mm Hg; lattice parameter reported at 293 K is 4.621 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
24*	657	Jun, C., Shaffer, and P.T.B.	1971	T	293-2856		91.8 Hf, 5.93 C (combined), 1.6 Zr, 0.31 C (free), 0.032 O, 0.03 Ti, 0.02 Nb, 0.02 Ta, 0.0054 Fe, 0.003 N, 0.0025 Cr, and 0.002 Ni; dimensions 0.32 cm x 0.32 cm x 7.1 cm cut from center of cylinder 7.62 cm O.D. x 7.67 cm long, which was hot pressed at 3646-3696 K, measurements obtained in argon atmosphere; zero-point correction of -0.003% determined by graphical interpolation.
25*	660	Samsonov, G.V. and Naumenko, V.Ya.	1969	L	298-1273	$HfC_{1.0}$	93.26 Hf and 19.25 C (total); cut from 8 mm diameter x 12-15 mm runs into 2.5 x 2.5 x 12-14 mm pieces; specimens formed by sintering process at 1.60 kg/cm^3 at 2373-2873 K for 15 min; annealed at 1.2×10^{-4} mm Hg at 2273-2473 K for 8 hr measured in argon atmosphere; reported error ± 2.0%.
26*	660	Samsonov, G.V. and Naumenko, V.Ya.	1969	L	298-1273	$HfC_{0.91}$	Similar to the above specimen in method but 93.99 Hf and 5.75 C (total).
27*	660	Samsonov, G.V. and Naumenko, V.Ya.	1969	L	298-1273	$HfC_{0.80}$	Similar to the above specimen in method but 94.73 Hf and 5.11 C (total).
28*	660	Samsonov, G.V. and Naumenko, V.Ya.	1969	L	298-1273	$HfC_{0.71}$	Similar to the above specimen in method but 95.42 Hf and 4.50 C (total).
29*	660	Samsonov, G.V. and Naumenko, V.Ya.	1969	L	298-1273	$HfC_{0.62}$	Similar to the above specimen in method but 95.55 Hf and 4.12 C (total).
30*	599	Samsonov, G.V., Grebenkina, V.G., and Klimenko, V.S.	1971	L	297-1273		Reported error 1.5%.

* Not shown in figure.

DATA TABLE 246. THERMAL LINEAR EXPANSION OF HAFNIUM CARBIDE HfC

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.003
1028	0.486
1283	0.679
1536	0.849
1791	1.033
2044	1.223
2299	1.433
CURVE 2	
300	0.005*
1273	0.690
1468	0.753
1669	0.936
1871	1.063
2074	1.235
2274	1.257
2376	1.425
2474	1.520
2574	1.632
2673	1.762
2778	1.821
2876	1.887
2978	1.968
CURVE 3‡	
783	0.314
1052	0.487
1161	0.567
1492	0.820
1825	1.063
2123	1.262
2320	1.412
CURVE 4	
293	0.000
768	0.308
970	0.444
1175	0.590
1387	0.727
1502	0.911
1591	0.924
1650	0.888
1707	1.037
1729	0.963
1830	1.052
1871	1.235
1989	1.297
2051	1.114
2069	1.199
2122	1.412
2126	1.228
2239	1.422
2307	1.403
2404	1.592
2533	1.704
2674	1.890
2961	2.085
3121	2.283
CURVE 5	
293	0.00*
633	0.15
710	0.19
810	0.24
1066	0.37
1291	0.50
1516	0.62
1722	0.75
1872	0.82
2022	0.91
2144	0.97
2288	1.05
2438	1.12
2655	1.18
2800	1.22
2927	1.27
CURVE 6	
2928	1.43
1644	0.68
1161	0.42
293	0.00*
CURVE 7	
293	0.00*
1027	0.40
1155	0.59
1458	0.79
1594	0.89
1727	0.99
1866	1.05
1977	1.12
2160	1.23
2272	1.31
2338	1.37
2460	1.45
2533	1.52
2627	1.58
2719	1.64
2855	1.71
2927	1.77
2983	1.83
3011	1.84
3033	1.84
3063	1.88
3066	1.88
3077	1.90
3055	1.87
3077	1.89
3111	1.92
3116	1.92
3122	1.93
3130	1.95
3133	1.97
3144	1.97
3155	1.98
3150	1.98
3144	1.99
3155	2.01
CURVE 8	
293	0.00*
763	0.27
953	0.40
1163	0.51
CURVE 9	
83	-0.0862
299	0.0021*
CURVE 10*	
83	-0.0905
299	0.0021
CURVE 11	
83	-0.0733
299	0.0021*
CURVE 12	
298	0.000*
344	0.028
393	0.056
442	0.083
482	0.111
528	0.139
564	0.162
605	0.185
673	0.234
694	0.250
712	0.266
742	0.280
758	0.292
787	0.313*
830	0.345
889	0.386
CURVE 13	
719	0.265*
643	0.218
561	0.164*
296	0.002*
CURVE 14	
301	0.005*
313	0.013
432	0.080
544	0.147
652	0.220*
766	0.296*
879	0.376
CURVE 15	
893	0.388*
862	0.373*
830	0.345*
805	0.339
789	0.331
716	0.279*
656	0.237
597	0.182
549	0.165
492	0.115*
CURVE 16	
351	0.025*
415	0.054
445	0.080*
485	0.106*
542	0.146*
568	0.161*
827	0.343*
CURVE 17	
795	0.316
723	0.262
712	0.260*
653	0.212*
531	0.134*
487	0.106*
CURVE 18*	
298	0.005
409	0.059
487	0.107
877	0.378
CURVE 19	
863	0.367
795	0.316*
719	0.264*
644	0.215*
564	0.162*
CURVE 20	
342	0.028*
394	0.058*
440	0.083*
484	0.114*
527	0.139*
570	0.168*
606	0.188*
733	0.289
804	0.321
836	0.343*
CURVE 21*	
797	0.320
725	0.275
645	0.217
551	0.164
CURVE 22	
300	0.004*
1273	0.612
CURVE 23*, †	
1073	0.00
1773	0.46
CURVE 24*	
293	0.000
1011	0.453
1068	0.470
1219	0.609
1265	0.609

* Not shown in figure.
† This curve is here reported using the first given temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 246. THERMAL LINEAR EXPANSION OF HAFNIUM CARBIDE HfC (continued)

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 24 (cont.)*		CURVE 24 (cont.)*		CURVE 27*		CURVE 30*	
1389	0.687	2587	1.691	298	0.003	293	0.000
1422	0.678	2728	1.843	1273	0.672	1293	0.660
1569	0.814	2759	1.835				
1630	0.863	2796	1.910	CURVE 28*			
1659	0.891	2856	1.934				
1721	0.911			298	0.003		
1785	1.002	CURVE 25*		1273	0.675		
1921	1.108						
2073	1.250	298	0.003	CURVE 29*			
2087	1.199	1273	0.670				
2164	1.318			*298*	*0.003*		
2311	1.476	CURVE 26*		1273	0.680		
2346	1.476						
2446	1.541	298	0.003				
2533	1.659	1273	0.670				
2564	1.659						

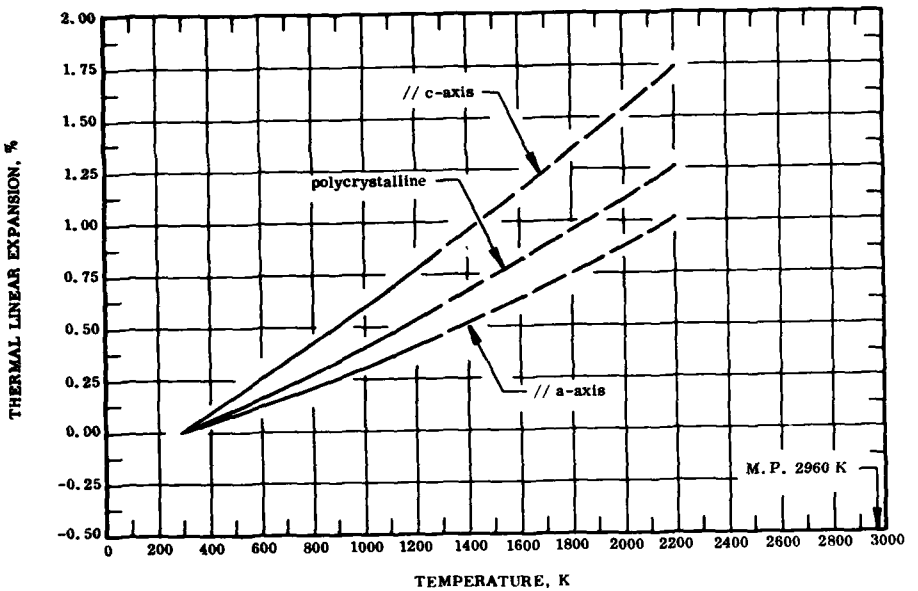
DATA TABLE 246. COEFFICIENT OF THERMAL LINEAR EXPANSION OF HAFNIUM CARBIDE HfC

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3*,‡	
783	6.03
1052	6.81
1161	7.76
1492	7.54
1825	7.04
2123	7.04
2320	7.07

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 247R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF DIMOLYBDENUM CARBIDE Mo_2C



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	5.1
300	0.005	0.012	0.007	5.1
400	0.043	0.091	0.059	5.3
500	0.083	0.175	0.114	5.5
600	0.124	0.260	0.169	5.6
700	0.166	0.345	0.226	5.8
800	0.210	0.430	0.283	5.9
900	0.256	0.515	0.342	6.1
1000	0.304	0.601	0.403	6.2
1200	0.406	0.777	0.530	6.5
1400	0.516†	0.964†	0.665†	6.8
1600	0.634†	1.152†	0.807†	7.1
1800	0.757†	1.343†	0.952†	7.4
2000	0.886†	1.538†	1.103†	7.7
2200	1.018†	1.738†	1.258†	8.0

† Provisional values.

REMARKS

The recommended values for the axial thermal expansion below 1300 K are based on the most recent measurements and those above 1300 K are extrapolated. The recommended values for the polycrystalline sample are calculated directly from the data for the a- and c-axis. This result is recommended in preference to the reported experimental data for polycrystalline samples on the suspicion that these samples exhibit partial preferential orientation and are not randomly oriented. These values are considered accurate to within ± 5% at temperatures below 1300 K and about ± 10% above. The recommended values are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.112 + 3.835 \times 10^{-4} T - 1.099 \times 10^{-8} T^2 + 4.299 \times 10^{-11} T^3$ (293-1200 K)

$\Delta L/L_0 = -0.0151 + 1.296 \times 10^{-4} T + 2.204 \times 10^{-7} T^2 - 3.002 \times 10^{-11} T^3$ (1200-2200 K)

// c-axis: $\Delta L/L_0 = -0.254 + 8.785 \times 10^{-4} T - 5.910 \times 10^{-8} T^2 + 3.535 \times 10^{-11} T^3$ (293-1200 K)

$\Delta L/L_0 = -0.350 + 9.918 \times 10^{-4} T - 7.018 \times 10^{-8} T^2 + 2.316 \times 10^{-11} T^3$ (1200-2200 K)

polycrystalline: $\Delta L/L_0 = -0.161 + 5.573 \times 10^{-4} T - 4.133 \times 10^{-8} T^2 + 4.741 \times 10^{-11} T^3$ (293-1200 K)

$\Delta L/L_0 = -0.127 + 4.215 \times 10^{-4} T + 1.180 \times 10^{-7} T^2 - 1.071 \times 10^{-11} T^3$ (1200-2200 K)

The tabulated values for the coefficient of thermal expansion are primarily calculated by differentiating the above equation for polycrystalline sample and are considered accurate to about ± 15%.

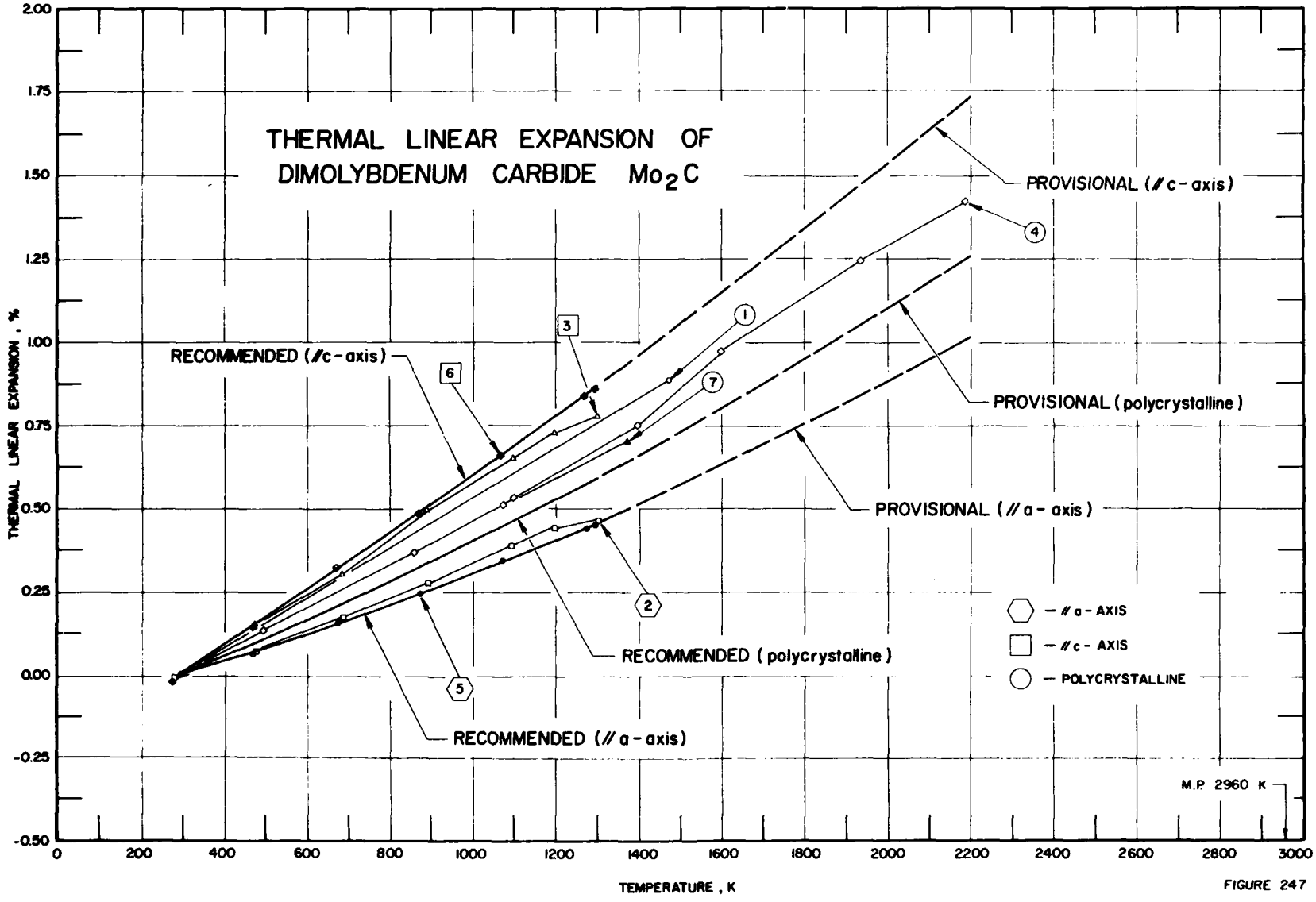

THERMAL LINEAR EXPANSION OF
DIMOLYBDENUM CARBIDE Mo_2C
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
PROVISIONAL (// c - axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// a - axis)
RECOMMENDED (// c - axis)
RECOMMENDED (polycrystalline)
RECOMMENDED (// a - axis)
1
2
3
4
5
6
7
— // a - AXIS
— // c - AXIS
— POLYCRYSTALLINE
M.P. 2960 K

FIGURE 247

SPECIFICATION TABLE 247. THERMAL LINEAR EXPANSION OF DIMOLYBDENUM CARBIDE Mo_2C

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	437	Frantsevich, I.N., Zhurakovshii, E.A., and Lyashchenko, A.B.	1968		293, 1473		Sample prepared from powder by the vacuum sintering of pressed block; metal-powder method used.
2	10	Mauer, F.B. and Bolz, L.H.	1957	X	273-1303		99.0 Mo_2C, < 0.05 Fe principal impurity; 5.85 C (theoretically 5.89 C) hexagonal crystal structure in commercial powder; expansion in vacuum measured along a-axis.
3	10	Mauer, F.B. and Bolz, L.H.	1957	X	273-1303		The above specimen; expansion measured along c-axis.
4	63	Pears, C.D. and Oglesby, S.	1963	L	293-2727		92.1 Mo, 5.51 C; < 0.1 N, elements found by semi-quantitative emission spectrography before exposure 2.0 Si, 0.6 Fe, 0.3 Ti, 0.2 Al, after exposure 92.4 Mo, 5.39 C and < 0.1 N; initial length 5.66 cm; hot pressed; specimen melted at 2727 K; run number E5; density in g cm^{-3} at 298 K before exposure 8.86 by ASTM method B311-58, 8.92 by wax-coating specimen, 8.96 by immersion in xylene, after exposure 8.56 by ASTM method, 8.59 by was-coating specimen, and 8.69 by immersion in xylene; measured in helium atmosphere; reported error 5%.
5	658	Ridley, N. and Stuart, H.	1970	X	273-1295		93.4 Mo, 6.1 C (total), 0.18 C (free), 0.02 O, 0.01 N, < 0.003 Fe, < 0.001 each Cr, Ni; powdered specimen; placed in 0.5 mm quartz capillary tube ~4 cm long; expansion measured along a-axis.
6	658	Ridley, N. and Stuart, H.	1970	X	273-1295		Same as the above specimen; expansion measured along c-axis.
7	599	Samsonov, V.G., Grebonkina, V.G., and Klimenko, V.S.	1971	L	293, 1373		Reported error -1.5%.

DATA TABLE 247. THERMAL LINEAR EXPANSION OF DIMOLYBDENUM CARBIDE Mo_2C

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.00
1473	0.88
CURVE 2	
273	-0.008
298	0.002*
479	0.072
685	0.171
891	0.274
1097	0.387
1200	0.437
1303	0.460
CURVE 3	
273	-0.013*
298	0.003*
479	0.152
685	0.303
891	0.496
1097	0.649
1200	0.724
1303	0.775
CURVE 4	
293	0.00*
494	0.13
857	0.37
1077	0.51
1102	0.53
CURVE 4 (cont.)	
1399	0.75
1699	0.97
1938	1.24
2194	1.42
2483	7.46*
2533	7.48*
2605	7.82*
2605	7.32*
2605	7.15*
2605	6.50*
2611	6.12*
2611	5.68*
2633	5.22*
2677	5.08*
2677	4.91*
2727	4.36*
CURVE 5	
273	-0.008*
293	0.000
473	0.071*
673	0.156
873	0.246
1073	0.340
1273	0.438
1295	0.449
CURVE 6	
273	-0.016
293	0.000*
473	0.149
673	0.317
873	0.488
CURVE 6 (cont.)	
1073	0.662
1273	0.837
1295	0.856
CURVE 7	
293	0.000
1373	0.704

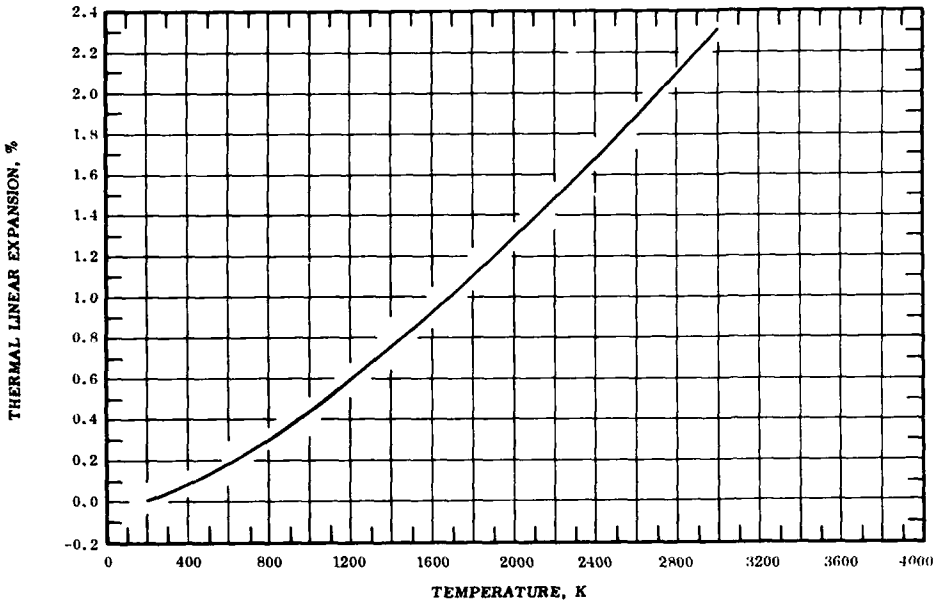
DATA TABLE 247. COEFFICIENT OF THERMAL LINEAR EXPANSION OF DIMOLYBDENUM CARBIDE Mo_2C

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 5*	
273	3.84
293	3.84
473	4.10
673	4.35
873	4.61
1073	4.82
1273	5.03
1295	5.07
CURVE 6*	
273	8.20
293	8.20
473	8.35
CURVE 6 (cont.)*	
673	8.48
873	8.63
1073	8.71
1273	8.80
1295	8.93

* Not shown in figure.

FIGURE AND TABLE NO. 248R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF NIOBIUM CARBIDE NbC



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	5.7
300	0.004	5.7
400	0.063	5.9
500	0.123	6.2
600	0.186	6.4
700	0.251	6.6
800	0.318	6.8
900	0.387	7.0
1000	0.458	7.2
1200	0.606	7.6
1400	0.762	8.0
1600	0.927	8.5
1800	1.101	8.9
2000	1.280	9.3
2200	1.470	9.7
2400	1.671	10.1
2600	1.879	10.6
2800	2.094	11.0
3000	2.319	11.4

REMARKS

The recommended values are based on the data for pure samples and are based on the most recent measurements. These values are considered accurate to within ± 5%. The disagreement of the recommended values with other measurements is probably due to the sample variation. The recommended values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.158 + 5.138 \times 10^{-4}\ T + 1.023 \times 10^{-7}\ T^2 + 5.718 \times 10^{-13}\ T^3$$

The tabulated values of the coefficient of thermal expansion are primarily based on the selected experimental data and also using the values obtained by differentiating the above equation. These values are considered accurate to about ± 7%.

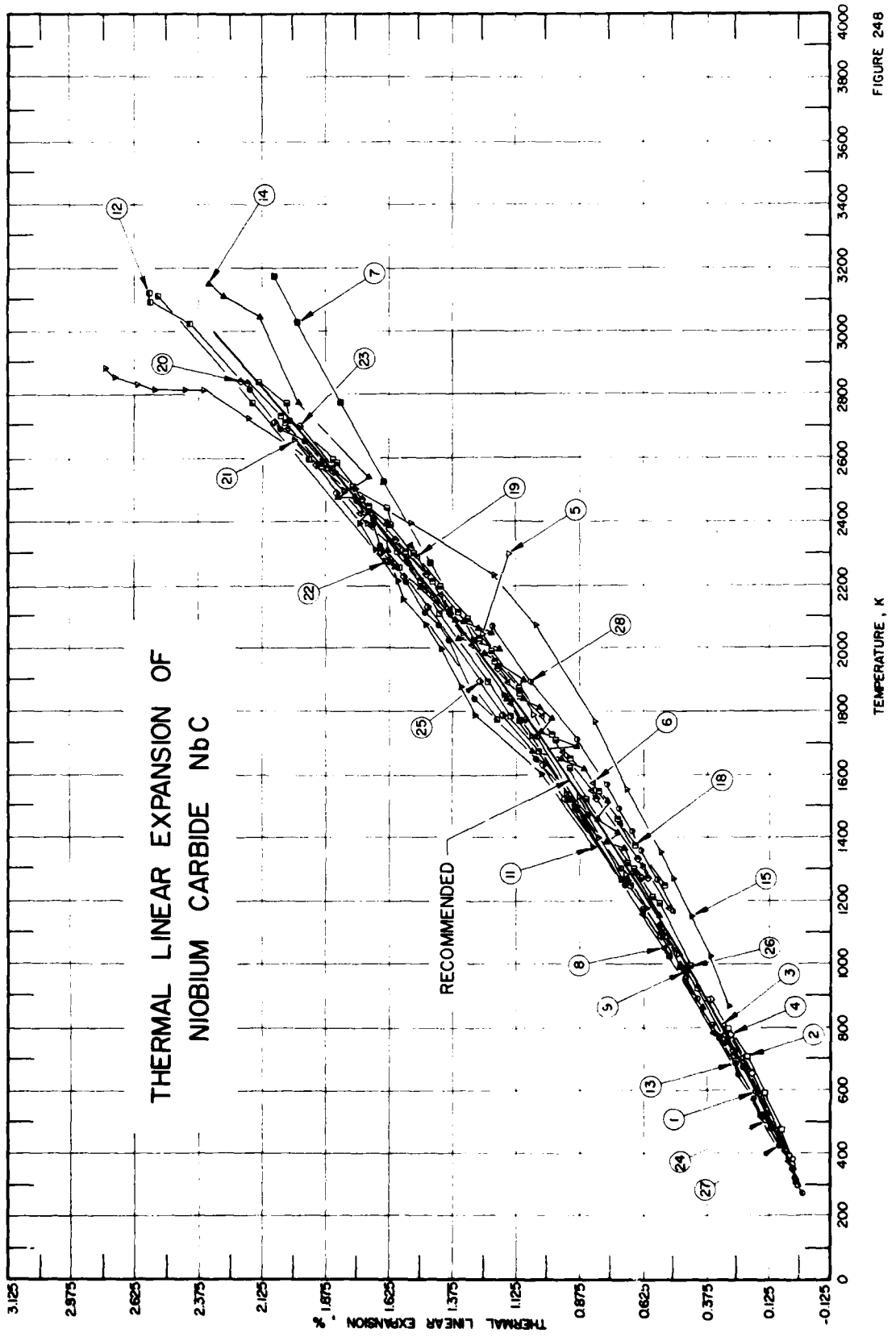

THERMAL LINEAR EXPANSION OF
NIOBIUM CARBIDE NbC
RECOMMENDED
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
3.125
2.875
2.625
2.375
2.125
1.875
1.625
1.375
1.125
0.875
0.625
0.375
0.125
-0.125
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000

FIGURE 248

SPECIFICATION TABLE 248. THERMAL LINEAR EXPANSION OF NIOBIUM CARBIDE NbC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	678	Kempter, C.P. and Storms, E.K.	1967	X	298-889	$NbC_{0.924}$	0.1 W, 0.05 Ta, 0.03 Zn, 0.03 Zr, and 0.01 Mo (spectrographic analysis); 89.18 Nb, 10.66 C, 0.044 O, and 0.002 Fe (chemical analysis); heating in vacuum sintered plug reduced to -325 mesh, outgassed for about 4 hr, in a vacuum (10^{-6} torr) above 1900 C, powder subjected to HCl extraction; using nickel radiation; lattice parameter reported at 298 K as 4.4681 Å; 4.4680 Å at 293 K determined by graphical extrapolation.
2	678	Kempter, C.P. and Storms, E.K.	1967	X	298-799	$NbC_{0.825}$	Similar to the above specimen except 0.1 W, 0.05 Ta, 0.03 Zn, 0.03 Zr, 0.01 Mo, and 0.01 V (spectrographic analysis); 89.4 Nb, 9.58 C, 0.042 O, and 0.002 Fe (chemical analysis); lattice parameter reported at 298 K as 4.4569 Å; 4.4568 Å at 293 K determined by graphical extrapolation.
3	678	Kempter, C.P. and Storms, E.K.	1967	X	298-805	$NbC_{0.766}$	Similar to the above specimen except 0.1 W, 0.05 Ta, 0.03 Zn, 0.03 Zr, and 0.01 Mo (spectrographic analysis) 90.69 Nb and 8.98 C (chemical analysis); lattice parameter reported at 298 K as 4.4469 Å; 4.4468 Å at 293 K determined by graphical extrapolation.
4	678	Kempter, C.P. and Storms, E.K.	1967	X	298-891	$NbC_{0.702}$	Similar to the above specimen except 0.1 W, 0.05 Ta, 0.03 each of V, Zn, and Zr, and 0.01 Mo (spectrographic analysis); 91.53 Nb, 8.31 C, and 0.0845 Fe (chemical analysis); lattice parameter reported at 298 K as 4.4313 Å; 4.4312 Å at 293 K determined by graphical extrapolation.
5	438	Houska, C.R.	1963	X	298-2304	$NbC_{0.88}$	99.32 NbC, 0.02 Cr, 0.02 Cu, 0.02 O, 0.03 N, 0.04 Ti, 0.05 B, 0.05 Ta, 0.05 Zr, and 0.08 C; sample made by reacting niobium with carbon at about 2300 C for three hr; cold pressed at 14 000 psi using camphor; sintered in vacuum at about 1800 C for two hr; CuKα radiation used; data obtained from (422) and (511/333); zero-point correction is -0.003% at 293 K determined by graphical interpolation.
6	437	Frantsevich, I.N., Zhurakovskii, E.A., and Lyashchenko, A.B.	1967		293, 1573		Sample prepared from powder of compound by the vacuum sintering of pressed block; metal-powder method used.
7	387	James, D.R. and Hjelm, L.N.	1964		309-3174		No details given; zero-point correction is -0.011% determined by graphical extrapolation.
8	423	Brizes, W.F.	1968	T	781-2526		High purity Nb rod inserted into graphite mold; diffusion annealed at 473 K below carbide-carbon eutectic temperature; m.p. 3773 K; expansion measured in 15 μ helium atmosphere.
9	424	Elliott, R.O. and Kempter, C.P.	1958	X	293-1121		98.5 pure, 0.5 free carbon; specimen from D. H. Sebell at Los Alamos Scientific Laboratories; 325 mesh powder sealed in silica capillary; lattice parameter reported at 293 K as 4.4691 Å.
10	425	Miccioli, B.R. and Shaffer, P.T.B.	1964	T	1368-2585		Expansion measured on Run 1.
11	425	Miccioli, B.R. and Shaffer, P.T.B.	1964	T	1256-2815		Expansion measured on Run 2.
12	425	Miccioli, B.R. and Shaffer, P.T.B.	1964	T	2258-3123		Expansion measured on Run 3.
13	10	Mauer, F.A. and Bolz, L.N.	1955	X	273-1723		98.5+ pure, < 1.0 Ti, < 0.1 Fe, Zr, < 0.01 any other impurity; expansion measured in helium atmosphere; zero-point correction of 0.014% determined by graphical interpolation.

SPECIFICATION TABLE 248. THERMAL LINEAR EXPANSION OF NIOBIUM CARBIDE NbC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
14	426	Paderno, Yu.B.	1965	T	867-3149		99.50 pure; hot pressed specimen 15 to 18 mm long, 8 mm diameter; expansion measured under atmosphere 10^{-2} mm Hg pressure.
15	318	Neel, D.S., Pears, C.D., and Oglesby, S., Jr.	1962		293-2883		Before exposure 88.9 Nb, 10.8 C, 0.2 N, 0.1 Fe, 0.1 other, after exposure 89.1 Nb, 10.7 C, and 0.2 N; initial length 2.9505 in., final length 2.9874 in.; Kennametal, Inc.; hot-pressed; Run SRI-E18; density in g cm^{-3} at (25 C) 298 K before exposure 7.68 by ASTM method B311-58, 7.74 by wax-coating specimen, 7.75 by immersion in xylene, after exposure 7.51 by wax-coating specimen and ASTM method and 7.53 by immersion in xylene; measured in helium atmosphere.
16*	318	Neel, D.S., et al.	1962		2883-293		Expansion measured in decreasing temperatures; zero-point correction of -1.14% determined by graphical interpolation.
17*	446	Panov, V.S. and Meerson, G.A.	1968	L	291,693		Hot pressed specimen 16 mm diameter x 5 to 10 mm high.
18	679	Speck, D.A. and Miccioli, B.R.	1968		1249-2737	Slug 17	0.3% deficient in carbon; hot pressed specimen, treated 30 min at 3273 K; density 6.627 g cm^{-3}; expansion measured perpendicular to pressing with increasing temperature.
19	679	Speck, D.A. and Miccioli, B.R.	1968		2731-1172	Slug 17	The above specimen; expansion measured with decreasing temperature.
20	679	Speck, D.A. and Miccioli, B.R.	1968		1274-2840	Slug 17	Similar to the above specimen; density 6.667 g cm^{-3}; expansion measured parallel to pressing with increasing temperature.
21	679	Speck, D.A. and Miccioli, B.R.	1968		2659-1172	Slug 17	The above specimen; expansion measured with decreasing temperature.
22	432	Miccioli, B.R. and Julien, H.P.	1965	T	300-3116		Hot pressed specimen; density 7.17 g cm^{-3}; expansion measured perpendicular to pressing.
23	432	Miccioli, B.R. and Julien, H.P.	1965	T	300-2701		Similar to the above specimen; density 7.39 g cm^{-3}; expansion measured parallel to pressing.
24	680	Brenton, R.F., Saunders, C.R., and Kempter, C.P.	1969	X	293-2716		$NbC_{0.969}$; hot pressed at 3323 K and 3400 psi for 10 min; density at 298 K 7.44 g cm^{-3}; expansion measured on first run.
25	680	Brenton, R.F., et al.	1969	X	293-2719		The above specimen; expansion measured on second run.
26	657	Jun, C.K. and Shaffer, P.T.B.	1971	T	293-2840		88.2 Nb, 10.7 C (combined), 0.34 C (free), 0.28 Ta, 0.06 W, 0.03 O, 0.02 N, 0.016 Fe, 0.075 Ti, 0.001 Cr, 0.001 Zr; dimensions were 1/8 in. x 1/8 in. x 2.8 in. cut from the center portion of a cylinder 3 in. O.D. x 3 in. long which was hot pressed at 3373-3423 K; measurements taken in argon atmosphere; zero-point correction is +0.013% determined by graphical interpolation.
27	658	Ridley, N. and Stuart, H.	1970	X	293-1285		88.0 Nb, 11.3 C (total), 0.3 O, 0.11 C (free), 0.05 N, <0.05 Fe, <0.05 Ta, <0.02 W, <0.01 each Cr, Ni, Ti; powdered specimen put in 0.5 mm diameter quartz capillary tube ~4 cm long.
28	681	Kagarlitskii, V.G., Gurvich, O.S., and Marmer, E.N.	1972	L	1173-2172		Specimen made by powder metallurgy technique then extruded.
29	682	Zil'berberg, V.G., Kutsenok, T.G., and Sharivker, S.Yu.	1970	L	293-1273		Specimen was plasma sprayed; density 6.95-7.05 g cm^{-3}, porosity 10-11.5%, dimensions 3.0 mm diameter x 5 mm long; measured in pure argon atmosphere; thickness of sprayed material 4-4.5 mm; measured parallel to grain; zero-point correction of -0.015% determined by graphical interpolation.

* Not shown in figure.

SPECIFICATION TABLE 248. THERMAL LINEAR EXPANSION OF NIOBIUM CARBIDE NbC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
30	682	Zil'berberg, V.G., Kutsenok, T.G., and Sharivker, S.Yu.	1970	L	293-1242		The above specimen; expansion measured perpendicular to grain; zero-point correction is -0.015% determined by graphical interpolation.
31*	660	Samsonov, G.V. and Navmenko, V.Ya.	1969	L	298, 1273		88.14 Nb, 11.31 C (total), cut from 8 mm x 12-15 mm rods into 2.5 x 2.5 x 12-14 mm bars; made by sintering process at 160 kg/cm^2 at 2373-2873 K for 15 min; annealed at 2273-2473 K, 8 hr at 1.2 x 10^{-4} mm Hg; measured in argon atmosphere; reported error was 2%.
32*	660	Samsonov, G.V. and Navmenko, V.Ya.	1969	L	298, 1273	$NbC_{0.92}$	Similar to the above specimen except 89.0 Nb, 10.62 C (total).
33*	660	Samsonov, G.V. and Navmenko, V.Ya.	1969	L	298, 1273	$NbC_{0.82}$	Similar to the above specimen except 90.34 Nb, 9.50 C (total).
34*	660	Samsonov, G.V. and Navmenko, V.Ya.	1969	L	298, 1273	$NbC_{0.76}$	Similar to the above specimen except 90.95 Nb, 8.92 C (total).
35*	660	Samsonov, G.V. and Navmenko, V.Ya.	1969	L	298, 1273	$NbC_{0.72}$	Similar to the above specimen except 91.25 Nb, 8.50 C (total).
36*	683	Green, J.L. and Leary, J.A.	1970	X	293-2073	$NbC_{0.97}$	$NbC_{0.97}$, 0.014 Fe, 0.0025 B; lattice parameter reported at 293 K as 4.4698 Å; zero-point correction is 0.53% determined by graphical interpolation.

* Not shown in figure.

DATA TABLE 248. THERMAL LINEAR EXPANSION OF NIOBIUM CARBIDE NbC

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.0022
381	0.0246
493	0.1051
594	0.1768
675	0.2260
777	0.2999
889	0.3670
CURVE 2	
298	0.0022*
393	0.0426
474	0.0718
594	0.1413
707	0.2131
799	0.2872
CURVE 3	
298	0.0022*
373	0.0449
392	0.0494*
479	0.0944
490	0.1079*
584	0.1641
703	0.2316
805	0.3035
CURVE 4	
298	0.0022*
406	0.0564
475	0.0947*
587	0.1647*
659	0.1985
786	0.2753
891	0.3565
CURVE 5	
298	0.003*
1030	0.487
1285	0.691
1535	0.875
1789	1.063
2043	1.263
2304	1.151
CURVE 6	
293	0.00*
1573	0.83
CURVE 7	
309	0.011
524	0.154
769	0.322
1023	0.524
1273	0.712
1523	0.914
1770	1.11
2024	1.29
2269	1.47
2524	1.65
2775	1.82
3023	1.99
3174	2.08
CURVE 8‡	
781	0.350
1049	0.542
1158	0.625
1490	0.888
1823	1.148
2123	1.381
2326	1.542
CURVE 9	
293	0.000*
771	0.3177*
973	0.4564
975	0.4609
1121	0.5638
CURVE 10	
1368	0.825
1602	1.026
1785	1.287
1876	1.343
1999	1.417
2073	1.485
2157	1.575
2213	1.598
CURVE 10 (cont.)	
2279	1.623
2313	1.676
2393	1.737
2427	1.707
2503	1.756
2558	1.836
2585	1.887
CURVE 11	
1256	0.699
1477	0.841
1646	1.050
1840	1.288
2021	1.388
2074	1.430
2115	1.487
2209	1.566
2326	1.659
2384	1.681
2462	1.752
2652	1.965
2693	2.064
2815	2.177
CURVE 12	
2258	1.593
2471	1.755*
2598	1.941
3026	2.419
3096	2.575
3123	2.575
CURVE 13	
273	-0.014
299	0.004*
480	0.110
687	0.254
894	0.407
1101	0.554
1308	0.713
1515	0.890
1723	1.046
CURVE 14	
867	0.385
998	0.477
1154	0.567
1294	0.655
1362	0.701
1381	0.771
1413	0.727
1460	0.806
1520	0.769
1620	0.858
1654	0.950
1678	1.066
1690	0.880
1737	1.029
1779	0.985
1808	1.036
1840	1.095
1840	1.161
1902	1.095
1983	1.252
1998	1.184
2030	1.351
2046	1.222
2062	1.276
1081	1.329
2093	1.369
2192	1.514
2252	1.601
2313	1.629
2398	1.629
2476	1.754
2477	1.826
2541	1.703
2778	1.981
3043	2.134
3114	2.278
3149	2.330
CURVE 15	
293	0.00*
866	0.28
1027	0.36
1149	0.43
1272	0.51
1352	0.56
1555	0.69
CURVE 15 (cont.)	
1766	0.82
2077	1.05
2233	1.21
2394	1.54
2588	1.93*
2727	2.18
2811	2.36
2811	2.43
2811	2.55
2833	2.62
2855	2.72
2883	2.74
CURVE 16*	
2883	1.60
2844	1.59
2844	1.58
2844	1.57
293	0.00
CURVE 17*	
291	-0.001
693	0.260
CURVE 18	
1249	0.546
1373	0.653
1460	0.726
1549	0.805
1614	0.882*
1657	0.915
1728	0.983
1854	1.108
1958	1.207
2031	1.274
2119	1.352
2204	1.458
2304	1.564
2441	1.710
2568	1.893
2737	2.059
CURVE 19	
2731	2.059*
2698	2.032
2562	1.848
2423	1.738
2289	1.522
2168	1.423
2006	1.300
1895	1.154
1781	1.026
1674	0.939
1549	0.828
1449	0.718
1309	0.624
1172	0.528
CURVE 20	
1274	0.607
1336	0.650
1419	0.720*
1529	0.816
1790	1.055*
1934	1.191
2119	1.380
2235	1.484
2343	1.601
2469	1.735
2833	2.186
2840	2.214
CURVE 21	
2659	2.000
2500	1.801
2395	1.708
2286	1.564
2168	1.456
2044	1.332
1855	1.171
1725	1.065
1547	0.928
1400	0.803
1263	0.689
1172	0.611

* Not shown in figure.

‡ Author's curve for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 248. THERMAL LINEAR EXPANSION OF NIOBIUM CARBIDE NbC (continued)

T	$\Delta L/L_0$
CURVE 22	
300	0.005*
1273	0.697*
1773	1.199
2273	1.637
2773	2.170
3116	2.538
CURVE 23	
300	0.004*
1273	0.627
1773	1.089
2273	1.556
2701	1.979
CURVE 24	
293	0.000*
508	0.133
712	0.261
921	0.406
1089	0.535
1251	0.678
1402	0.797*
1535	0.924*
1673	1.038
1784	1.149
1898	1.235
2028	1.341*
2117	1.426
2209	1.513
2307	1.598
2404	1.683
2488	1.772*
2562	1.870
2659	1.954*
2716	2.047
CURVE 25	
293	0.000*
350	0.029
524	0.132
721	0.268
918	0.414*
1090	0.554
1251	0.678*
1402	0.804*
CURVE 25 (cont.)	
1530	0.931
1631	1.025
1784	1.178
1898	1.271
2029	1.393*
2130	1.478
2221	1.571
2307	1.653
2400	1.742*
2489	1.828
2574	1.914
2650	2.010*
2719	2.079
CURVE 26	
293	0.000*
995	0.447
1197	0.564
1218	0.585
1261	0.617*
1303	0.633
1324	0.665
1426	0.743*
1521	0.853
1591	0.863
1632	0.907
1718	0.965
1740	1.048*
1839	1.134*
1877	1.107
1991	1.218
1991	1.264*
2097	1.313
2097	1.356*
2192	1.427
2222	1.470*
2308	1.529
2308	1.571*
2386	1.679
2443	1.652
2505	1.759
2583	1.829
2598	1.849
2718	2.016
2771	2.025
2840	2.143
CURVE 27	
293	0.000*
327	0.020
359	0.040*
382	0.054*
432	0.085
487	0.125*
578	0.186
653	0.242
755	0.302
810	0.351
898	0.418*
951	0.456
1019	0.510*
1094	0.562*
1174	0.617
CURVE 28‡	
1173	0.513
1274	0.572
1359	0.629
1419	0.670
1498	0.723
1573	0.773
1716	0.878
1899	1.028
2072	1.165
2172	1.244
CURVE 29*	
293	0.000
364	0.040
419	0.060
473	0.091
502	0.134
566	0.174
647	0.221
780	0.288
862	0.361
947	0.413
1073	0.491
1163	0.566
1273	0.631
CURVE 30*	
293	0.000
364	0.040
473	0.135
555	0.215
651	0.302
734	0.380
744	0.455
806	0.495
926	0.609
983	0.680
1072	0.725
1151	0.771
1242	0.808
CURVE 30 (cont.)	
1273	0.690
CURVE 31*	
298	0.003
1273	0.690
CURVE 32*	
298	0.003
1273	0.685
CURVE 33*	
298	0.003
1273	0.682
CURVE 34*	
298	0.003
1273	0.687
CURVE 35*	
298	0.003
1273	0.695
CURVE 36*	
293	0.000
1073	0.519
1273	0.669
1473	0.807
1673	0.954
1873	1.117
2073	1.217

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

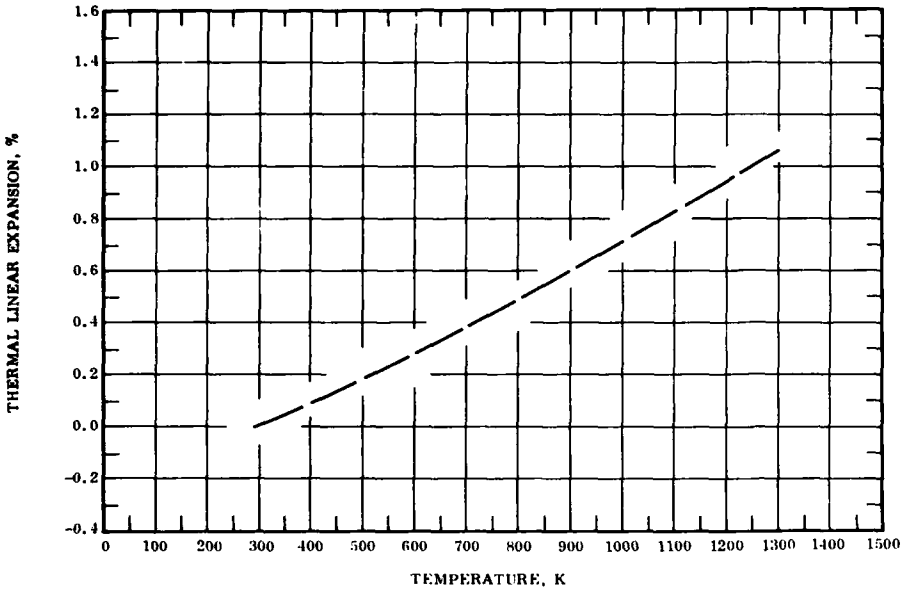
DATA TABLE 248. COEFFICIENT OF THERMAL LINEAR EXPANSION OF NIOBIUM CARBIDE NbC

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 8*,‡	
781	7.06
1049	7.30
1158	7.89
1490	7.95
1823	7.65
2123	7.89
2326	7.99
CURVE 28*,‡	
1173	5.15
1274	6.51
1359	6.88
1419	6.76
1498	6.76
1573	6.52
1716	8.20
1899	8.19
2072	7.62
2172	8.29

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 249R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF PLUTONIUM CARBIDE PuC



PROVISIONAL VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

T	$\Delta L/L_0$	α
293	0.000	8.2
300	0.007	8.3
400	0.092	8.9
500	0.184	9.4
600	0.280	9.9
700	0.381	10.3
800	0.486	10.7
900	0.596	11.1
1000	0.708	11.4
1100	0.824	11.7
1200	0.943	12.0
1300	1.063	12.2

REMARKS

The provisional values are based on the data for pure samples and are considered accurate to within ± 7% at temperatures below 700 K and to within ± 15% above 700 K. The disagreement of the experimental data with the provisional values especially above 700 K is probably due to sample variation. The provisional values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.212 + 6.283 \times 10^{-4}\ T + 3.621 \times 10^{-7}\ T^2 - 6.959 \times 10^{-11}\ T^3$$

The tabulated values of the coefficient of thermal expansion are primarily calculated by differentiating the above equation and are considered accurate to about ± 15%.

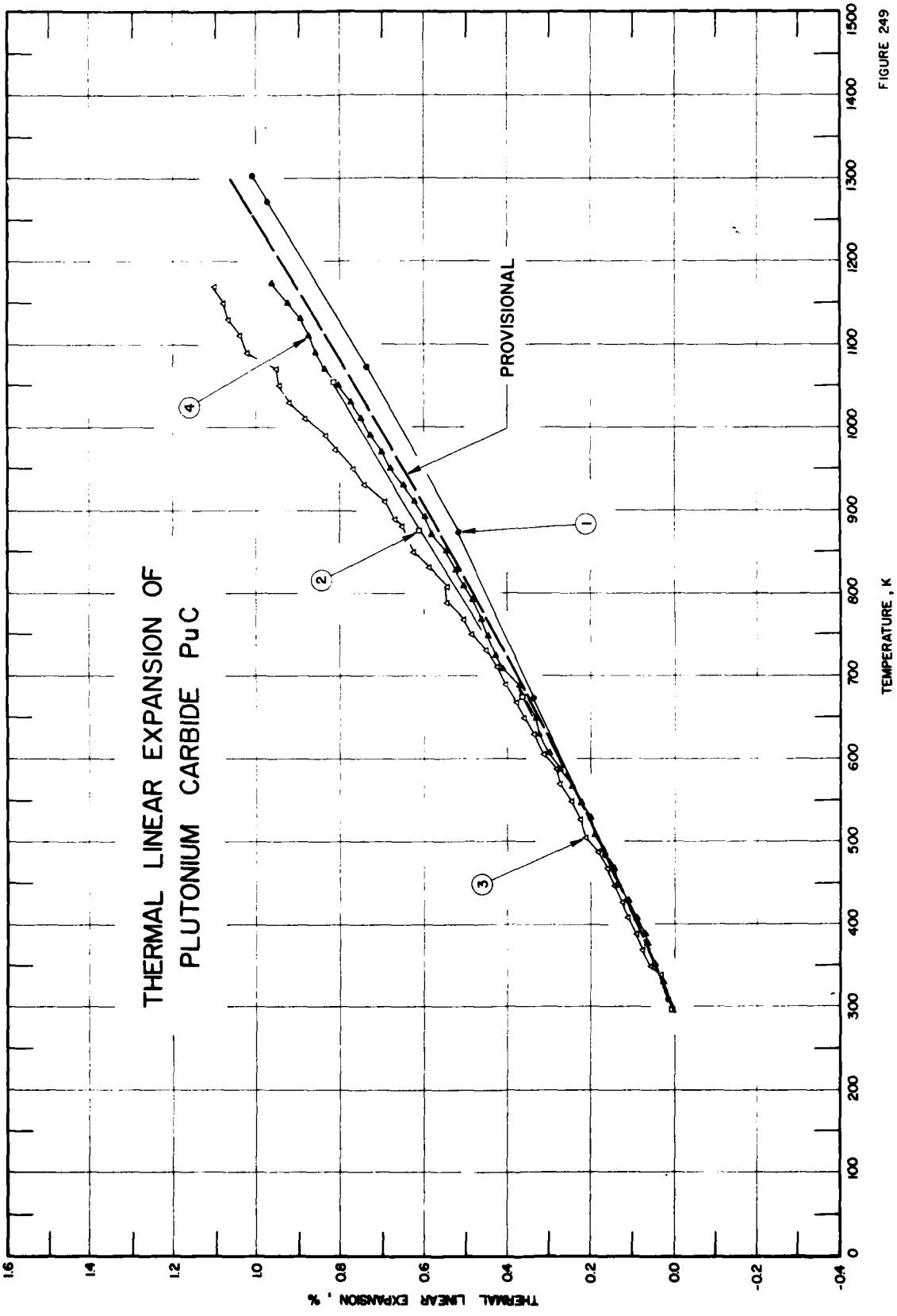

THERMAL LINEAR EXPANSION OF
PLUTONIUM CARBIDE PuC
PROVISIONAL
1
2
3
4
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 249

SPECIFICATION TABLE 249. THERMAL LINEAR EXPANSION OF PLUTONIUM CARBIDE PuC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	137	Kruger, O. L. and Moser, J. B.	1965	L	310-1304		No details given; zero-point correction is -0.016% determined by graphical interpolation.
2	684	Pallmer, P.G.	1962	X	298-1053		Face-centered-cubic structure; specimen prepared by heating a mixture of plutonium hydride and carbon and crushing the sintered pellet; percent expansion calculated from lattice parameters; measured by x-ray diffraction.
3	685	Ogard, A. E., Land, C. C., and Leary, J. A.	1962	L	300-1170		$PuC_{0.85}$ (45.8 a/o carbon); cylindrical specimen, 25.4 cm long by 6.35 mm in diameter, fabricated by grinding the annealed castings with silicon carbide grinding wheels; sample prepared by arc melting cylinders of plutonium metal and spectrographic grade graphite rod in a zirconium gittered helium-argon atmosphere; material inverted, remelted at least six times and held in the molten state for about 1 min. during each melting cycle; expansion with increasing temperature, first run.
4	685	Ogard, A. E., et al.	1962	L	293-1173		The above specimen; second run; expansion with increasing temperature.
5*	685	Ogard, A. E., et al.	1962	L	293-1173		$PuC_{0.83}$ (45.4 a/o carbon); similar to the above specimen; specimen rapidly cooled by exposing the dilatometer tube to room temperature and heated slowly 2 C/min.
6*	685	Ogard, A. E., et al.	1962	L	293-1173		The above specimen; another run.
7*	685	Ogard, A. E., et al.	1962	L	1165-293		$PuC_{0.82}$ (44.9 a/o carbon); cylindrical specimen; 25.4 mm long by 6.35 mm in diameter, fabricated by grinding the annealed castings with silicon carbide grinding wheels; sample prepared by arc melting cylinders of plutonium metal and spectrographic grade graphite rod in a zirconium gettered helium-argon atmosphere; material inverted, remelted at least six times and held in the molten state for about 1 min. during each melting cycle; expansion measured with decreasing temperature 2 C/min.
8*	685	Ogard, A. E., et al.	1962	L	293-1173		Similar to the above specimen; rapidly cooled from 1173 K (by exposing the dilatometer tube to room temperature) then heated.
9*	685	Ogard, A. E., et al.	1962	L	293-927		Similar to the above specimen; expansion with increasing temperature of specimen had been cooled rapidly from 1173 K (by exposing the dilatometer tube to room temperature).
10*	685	Ogard, A. E., et al.	1962	L	927-307		The above specimen; same run; expansion measured with decreasing temperature 2 C/min.; zero-point correction is -0.619% determined by graphical interpolation.
11*	685	Ogard, A. E., et al.	1962	L	304-1073		Similar to the above specimen; specimen slowly cooled and subsequent expansion curve with increasing temperature; zero-point correction is -0.010% determined by graphical interpolation.
12*	685	Ogard, A. E., et al.	1962	L	315-1169		Similar to the above specimen; rapidly cooled, then slowly heated (2 C/min.) until contraction began, held at constant temperature 583 K until contraction stopped before heating continued to 1173 K; zero-point correction is -0.029% determined by graphical interpolation.

* Not shown in figure.

SPECIFICATION TABLE 249. THERMAL LINEAR EXPANSION OF PLUTONIUM CARBIDE PuC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
13*	685	Ogard, A.E., Land, C.C., and Leary, J.A.	1962	L	293-1152		$PuC_{0.76}$ (43.2 a/o carbon); similar to the above specimen; specimen had been cooled rapidly by exposing the dilatometer tube to room temperature; expansion measured with increasing temperature; zero-point correction is 0.036% determined by graphical interpolation.
14*	685	Ogard, A.E., et al.	1962	L	1152-302		The above specimen; expansion measured with decreasing temperature, rate 2 C/min.; zero-point correction is 0.930% determined by graphical interpolation.
15*	685	Ogard, A.E., et al.	1962	L	293-983		Similar to the above specimen; specimen had been cooled slowly, 2 C/min.; expansion measured with increasing temperature; zero-point correction is 0.075% determined by graphical interpolation.
16*	685	Ogard, A.E., et al.	1962	L	985-293		The above specimen; expansion measured with decreasing temperature, rate 2 C/min.; zero-point correction is 0.320% determined by graphical interpolation.
17*	685	Ogard, A.E., et al.	1962	L	293-1135		$PuC_{0.70}$ (41.1 a/o carbon); similar to the above specimen; expansion measured with increasing temperature of specimen had been slowly cooled; rate 2 C/min.
18*	685	Ogard, A.E., et al.	1962	L	1131-419		The above specimen; expansion measured with decreasing temperature by exposing the dilatometer tube to room temperature; zero-point correction is -0.26% determined by graphical interpolation.

* Not shown in figure.

DATA TABLE 249. THERMAL LINEAR EXPANSION OF PLUTONIUM CARBIDE PuC

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
310	0.016
473	0.165
674	0.339
874	0.518
1075	0.734
1272	0.976
1304	1.013
CURVE 2	
298	0.003
673	0.365
873	0.607
1053	0.808
CURVE 3	
300	0.002*
308	0.018*
329	0.037
348	0.058
368	0.077
388	0.093
407	0.106
427	0.123
447	0.144
466	0.159
487	0.182
507	0.211
526	0.231
546	0.247
567	0.272
586	0.281
607	0.312
629	0.339
648	0.360
668	0.379
687	0.405
710	0.424
727	0.456
748	0.485
768	0.509
788	0.543
808	0.545
829	0.590

T	$\Delta L/L_0$
CURVE 3 (cont.)	
847	0.621
870	0.652
888	0.675
910	0.698
929	0.743
950	0.771
971	0.810
989	0.830
1009	0.885
1030	0.922
1052	0.944
1070	0.955
1090	1.022
1110	1.042
1129	1.071
1150	1.081
1170	1.102
CURVE 4	
293	0.000*
309	0.018*
329	0.037*
350	0.050
368	0.064
389	0.075
407	0.090
429	0.111
447	0.139
467	0.152
489	0.168
508	0.191
528	0.198
546	0.221
568	0.241
588	0.275
607	0.300
627	0.321
649	0.330
670	0.337*
688	0.371
709	0.410
728	0.424
748	0.443
769	0.460

T	$\Delta L/L_0$
CURVE 4 (cont.)	
791	0.481
810	0.501
827	0.524
850	0.555
870	0.580
891	0.595
910	0.621
930	0.650
950	0.681
970	0.705
990	0.731
1013	0.751
1031	0.776
1051	0.804
1070	0.838
1090	0.861
1111	0.871
1131	0.897
1150	0.931
1173	0.962
CURVE 5*	
293	0.000
311	0.008
332	0.015
352	0.040
372	0.069
394	0.087
412	0.095
432	0.105
453	0.135
472	0.177
492	0.218
512	0.238
532	0.264
552	0.280
572	0.285
593	0.297
613	0.310
633	0.238
654	0.121
676	0.000
694	-0.091
714	-0.082

T	$\Delta L/L_0$
CURVE 5 (cont.)*	
736	-0.009
753	0.088
776	0.198
794	0.344
813	0.478
836	0.570
852	0.599
875	0.610
893	0.640
913	0.661
933	0.680
953	0.698
972	0.710
991	0.745
1011	0.757
1030	0.784
1050	0.809
1071	0.816
1092	0.837
1108	0.867
1128	0.894
1148	0.904
1173	0.921
CURVE 6*	
293	0.000
314	0.006
330	0.022
354	0.040
371	0.054
392	0.064
412	0.092
432	0.107
453	0.132
472	0.151
493	0.160
513	0.179
532	0.210
549	0.226
574	0.241
595	0.250
611	0.237
633	0.211
654	0.160

T	$\Delta L/L_0$
CURVE 6 (cont.)*	
674	0.096
692	0.062
714	0.076
734	0.151
752	0.244
775	0.350
794	0.457
815	0.542
832	0.589
854	0.618
874	0.637
892	0.665
915	0.679
934	0.708
953	0.727
972	0.747
995	0.769
1014	0.783
1032	0.805
1049	0.833
1074	0.855
1093	0.870
1111	0.896
1133	0.928
1151	0.951
1173	0.966
CURVE 7*	
1165	2.014
1147	2.001
1126	1.979
1107	1.955
1087	1.929
1069	1.908
1050	1.885
1028	1.862
1010	1.840
991	1.820
969	1.795
949	1.770
929	1.751
909	1.721
890	1.692
871	1.671

T	$\Delta L/L_0$
CURVE 7 (cont.)*	
850	1.656
830	1.561
809	1.350
793	1.130
770	0.960
752	0.883
735	0.770
716	0.682
696	0.608
673	0.458
655	0.411
635	0.369
614	0.336
593	0.302
575	0.274
552	0.257
532	0.225
517	0.197
492	0.132
476	0.130
451	0.130
435	0.115
415	0.102
393	0.095
374	0.068
352	0.049
335	0.030
314	0.015
293	0.000
CURVE 8*	
293	0.000
336	0.018
355	0.040
370	0.058
394	0.078
412	0.094
434	0.116
454	0.136
473	0.154
493	0.176
515	0.191
532	0.211
552	0.226

* Not shown in figure.

DATA TABLE 249. THERMAL LINEAR EXPANSION OF PLUTONIUM CARBIDE PuC (continued)

CURVE 8 (cont.)*

T	$\Delta L/L_0$
572	0.231
595	0.214
610	0.159
632	0.101
648	0.059
674	0.019
693	0.012
712	0.067
733	0.181
752	0.301
772	0.424
789	0.523
810	0.594
829	0.619
851	0.643
870	0.677
889	0.693
911	0.717
931	0.747
949	0.757
971	0.789
991	0.817
1009	0.838
1029	0.867
1053	0.883
1072	0.905
1092	0.918
1109	0.948
1128	0.968
1152	1.001
1173	1.017

CURVE 9*

T	$\Delta L/L_0$
293	0.000
311	0.007
327	0.014
349	0.038
370	0.049
388	0.067
407	0.096
428	0.102
447	0.128
469	0.145
489	0.166
509	0.188
530	0.206
547	0.226

CURVE 9 (cont.)*

T	$\Delta L/L_0$
568	0.249
587	0.249
596	0.228
609	0.211
619	0.188
628	0.165
637	0.144
648	0.117
657	0.097
667	0.079
678	0.069
688	0.057
701	0.067
710	0.088
719	0.118
729	0.170
739	0.226
748	0.279
758	0.331
766	0.387
780	0.436
786	0.494
794	0.534
808	0.564
818	0.577
829	0.590
842	0.590
845	0.600
867	0.635
890	0.664
909	0.676
927	0.701

CURVE 10*

T	$\Delta L/L_0$
927	1.320
906	1.317
887	1.300
864	1.274
848	1.254
840	1.247
830	1.234
817	1.222
804	1.205
792	1.194
781	1.178
767	1.159
751	1.146

CURVE 10 (cont.)*

T	$\Delta L/L_0$
736	1.125
729	1.110
716	1.095
707	1.085
697	1.071
684	1.062
676	0.994
667	0.893
657	0.802
648	0.734
640	0.645
631	0.592
621	0.534
609	0.498
603	0.473
589	0.439
567	0.393
549	0.363
530	0.339
512	0.311
492	0.283
472	0.256
449	0.235
430	0.205
410	0.182
391	0.159
370	0.132
351	0.114
332	0.084
307	0.030

CURVE 11*

T	$\Delta L/L_0$
304	0.010
314	0.019
333	0.039
352	0.057
373	0.077
413	0.127
432	0.154
453	0.178
474	0.200
490	0.226
510	0.256
530	0.274
555	0.304
581	0.321
603	0.335

CURVE 11 (cont.)*

T	$\Delta L/L_0$
628	0.339
642	0.331
654	0.325
668	0.325
692	0.347
70[illegible]	0.369
71[illegible]	0.401
720	0.455
731	0.510
740	0.569
752	0.605
759	0.715
769	0.802
779	0.880
793	0.977
801	1.056
808	1.139
823	1.200
834	1.223
839	1.236
851	1.252
860	1.264
871	1.278
888	1.283
912	1.321
930	1.339
949	1.362
972	1.388
995	1.408
1011	1.439
1035	1.450
1051	1.478
1071	1.500
1089	1.525
1111	1.550
1133	1.569
1155	1.601
1073	1.608

CURVE 12*

T	$\Delta L/L_0$
315	0.029
327	0.045
345	0.059
364	0.078
383	0.097
394	0.110
408	0.120

CURVE 12 (cont.)*

T	$\Delta L/L_0$
422	0.136
429	0.147
441	0.160
456	0.170
472	0.188
485	0.205
504	0.222
519	0.233
529	0.246
552	0.256
568	0.242
577	0.203
577	-0.662
589	-0.654
596	-0.643
607	-0.630
618	-0.603
627	-0.577
638	-0.532
651	-0.489
660	-0.446
669	-0.393
677	-0.345
689	-0.292
699	-0.219
707	-0.154
717	-0.062
727	0.021
740	0.092
751	0.184
759	0.264
771	0.347
778	0.438
787	0.501
797	0.584
806	0.624
822	0.645
837	0.664
847	0.674
857	0.682
867	0.700
885	0.723
905	0.750
925	0.768
947	0.798
969	0.822
987	0.845
1007	0.869

CURVE 12 (cont.)*

T	$\Delta L/L_0$
1028	0.889
1047	0.900
1067	0.921
1108	0.971
1127	0.987
1149	1.004
1169	1.020

CURVE 13*

T	$\Delta L/L_0$
293	0.000
354	0.028
422	0.084
508	0.191
566	0.239
587	0.216
663	0.463
682	0.500
723	0.402
781	0.285
824	0.834
840	0.874
957	0.988
1090	1.140
1152	1.231

CURVE 14*

T	$\Delta L/L_0$
1152	2.125
1090	2.034
957	1.882
857	1.767
732	1.633
719	1.598
710	1.530
687	0.930
669	0.732
648	0.555
604	0.406
561	0.342
503	0.291
302	0.004

CURVE 15*

T	$\Delta L/L_0$
293	0.000
337	0.043
423	0.164

* Not shown in figure.

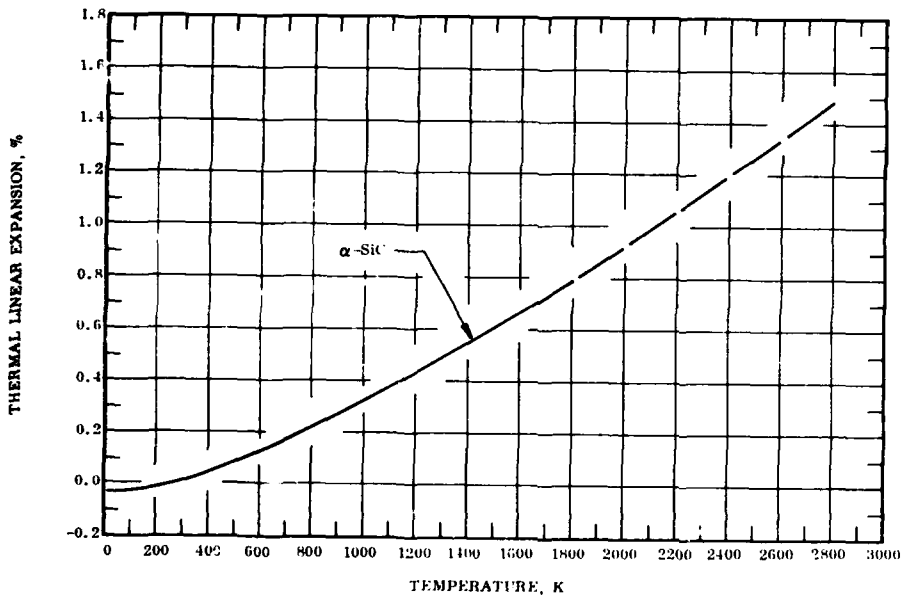
DATA TABLE 249. THERMAL LINEAR EXPANSION OF PLUTONIUM CARBIDE PuC (continued)

T	$\Delta L/L_0$
CURVE 15 (cont.)*	
503	0.289
556	0.347
598	0.376
636	0.405
674	0.452
709	0.517
733	0.604
755	0.774
774	0.979
792	1.193
817	1.524
831	1.740
843	1.788
919	1.856
983	1.925
CURVE 16*	
985	2.167
876	2.014
819	1.950
781	1.907
718	1.812
721	1.582
714	1.294
696	0.904
670	0.659
634	0.492
590	0.373
540	0.280
416	0.130
293	0.000
CURVE 17*	
293	0.00
663	0.67
719	0.84
766	1.04
799	1.29
821	1.63
843	2.22
852	2.71
862	2.79
882	2.81
928	2.80
991	2.86
1101	3.03
1135	3.06
CURVE 18*	
1131	3.31
930	2.94
915	2.88
889	2.78
829	2.65
813	2.58
813	1.87
801	1.69
751	1.23
683	0.85
638	0.71
419	0.26

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

FIGURE AND TABLE NO. 250R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SILICON CARBIDE SiC



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
5	-0.030	0.01
10	-0.030	0.02
25	-0.030	0.03
50	-0.030	0.06
75	-0.030	0.09
100	-0.030	0.14
150	-0.029	0.4
200	-0.024	1.5
250	-0.013	2.8
293	-0.000	3.3
300	0.002	3.4
400	0.041	4.0
500	0.082	4.2
600	0.126	4.5
700	0.171	4.7
800	0.219	4.9
900	0.269	5.1
1000	0.321	5.3
1200	0.431	5.6
1400	0.546	6.0
1600	0.668	6.2
1800	0.795	6.5
2000	0.926†	6.7
2200	1.061†	6.9
2400	1.199†	7.0
2600	1.340†	7.1
2800	1.481†	7.1

† Provisional values.

REMARKS

The recommended values are based on the data for polycrystalline samples (curves 1, 4, 19, and 22) and are considered accurate to within ± 5% at temperatures below 1800 K and to within ± 10% above 1800 K. The disagreement of the recommended values with several other measurements is primarily due to the sample variation. The recommended values are represented approximately by the following equation:

$$\Delta L/L_0 = -9.913 \times 10^{-2} + 2.970 \times 10^{-4}\, T + 1.388 \times 10^{-7}\, T^2 - 1.548 \times 10^{-11}\, T^3 \qquad (293\text{–}2800\ K)$$

The tabulated values of the coefficient of thermal expansion are obtained primarily by differentiating the above equation and are considered accurate to about ± 10%.

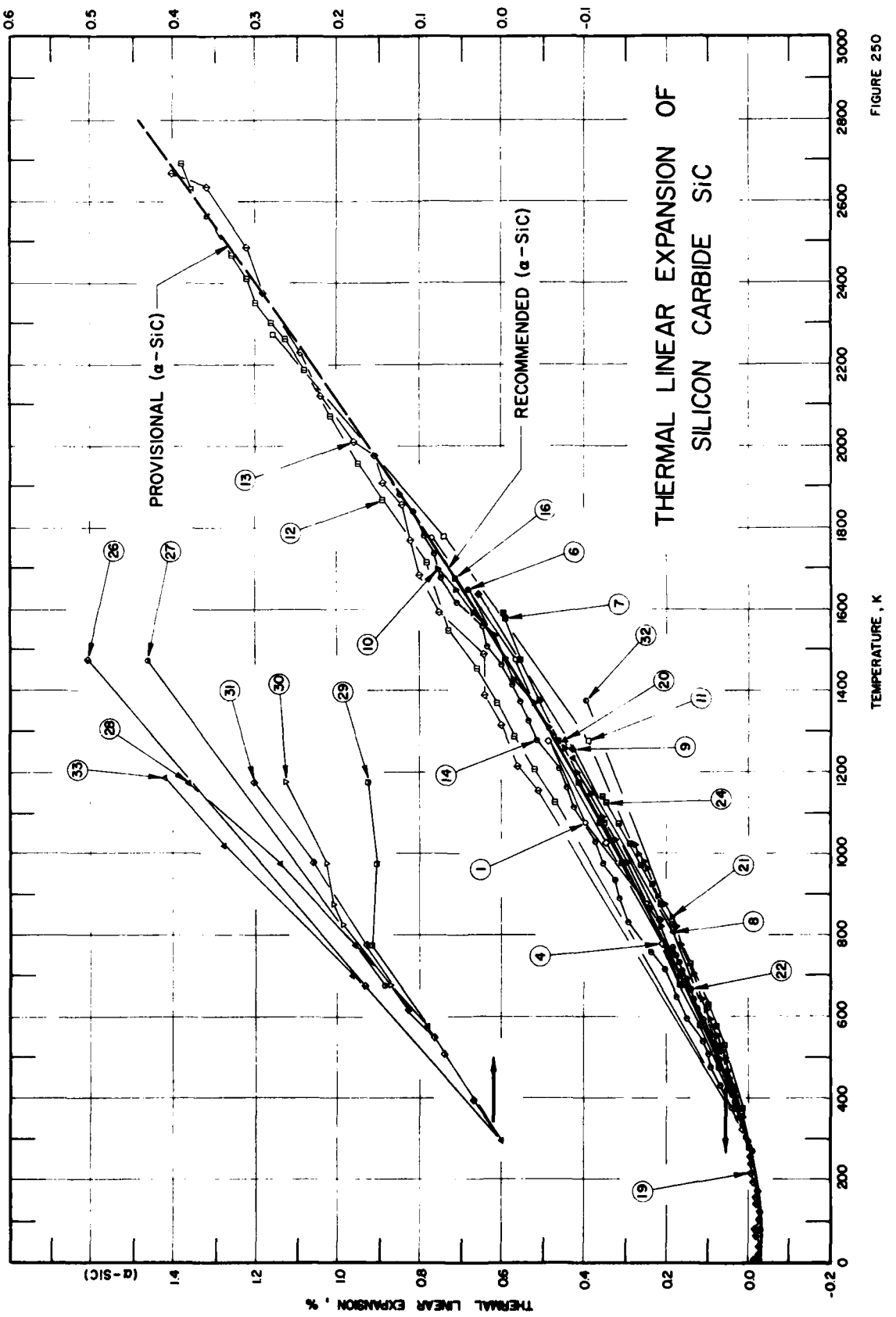

THERMAL LINEAR EXPANSION OF
SILICON CARBIDE SiC
PROVISIONAL (α-SiC)
RECOMMENDED (α-SiC)
THERMAL LINEAR EXPANSION , %
(α-SiC)
TEMPERATURE , K

FIGURE 250

SPECIFICATION TABLE 250. THERMAL LINEAR EXPANSION OF SILICON CARBIDE SiC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1	Whittemore, O. J., Jr. and Ault, N. N.	1956	T	293-1773		Specimen 7 in. long with cross section 0. 5 x 0. 5 in. ; the ends sawed at a rake and to a point; recrystallized; heating element.
2*	1	Whittemore, O. J., Jr. and Ault, N. N.	1956	T	293-1773		Similar to the above specimen; clay-bonded.
3*	1	Whittemore, O. J., Jr. and Ault, N. N.	1956	T	293-1773		Similar to the above specimen: bonded glazed brick.
4	387	James, D. R. and Helms, L. N.	1964		320-2023		No details given; zero-point correction of 0. 012% determined by graphical extrapolation.
5*	451	Wilson, R. E., Coffin, L. B. and Tinklepaugh, J. R.	1955	L	293-1673		98. 0 pure, 2. 0 Al added: expansion measured in helium atmosphere: data is average of four best runs: data smoothed by author.
6	452	Taylor, K. M. and Aiken, D. B.	1959		266, 1644		Self-bonded, all silicon carbide; containing few percent of free silicon as dispersed phase; same composition and characteristics as the KT Silicon Carbide refractory produced by the Carborundum Co.
7	72	Fulkerson, S. D.	1959	L	273-1588	Body "B"	Bar specimen, 0. 66 x 0. 66 x 2. 54 in. ; siliconized; expansion measured in static argon atmosphere; zero-point correction of -0. 006% determined by graphical interpolation.
8	453	Powers, D. J.	1962	L	299-1231	Foam	Specimen dimensions 0. 5 in. diameter by 3 in. long: obtained from Carborundum Co. ; density 38 lbs. ft^{-3}; expansion measured in vacuum of 0. 5 in. Hg up to 1200 K and with slight purge of argon above 1200 K.
9	454	Nowak, J. M.	1961	L	299-1635		Dense silicon carbide: dimension 3 in. long by 0. 5 in. diameter.
10	67	Seibel, R. D. and Mason, G. L.	1958	L	293-1699	8-9 free silicon	Grain size 0. 002-0. 003 in. and 0. 006-0. 008 in. ; specimen obtained from Carborundum Co. in 1956; density 3. 0 g cm^{-3}; expansion measured in a vacuum of the order 10^{-6} to 10^{-5} mm Hg and at heating rate about 2-3 C per minute.
11	429	Shaffer, P. T. B. and Mark, S. D.	1963	L	293-2273		Expansion measured in inert atmosphere with pressure of approximately 1 in. water above atmospheric pressure.
12*	70	Engberg, C. J. and Zehms, E. H.	1958	T	293-2697	Sample No. BF-F2	Specimen hot pressed; density 2. 50 g cm^{-3}; expansion measured in argon atmosphere.
13*	70	Engberg, C. J. and Zehms, E. H.	1958	T	2697-293	Sample No. BF-F2	The above specimen; expansion measured with decreasing temperature.
14	455	Fieldhouse, I. B., Hedge, J. C., Lang, J. I. and Waterman, T. E.	1958	T	299-1879		98+ pure specimen; zero-point correction of 0. 003% determined by graphical extrapolation.
15*	456	Mark, S. D. and Emanuelson, R. C.	1958	L	298-1273		Expansion measurement calibrated with fused silica.
16	456	Mark, S. D. and Emanuelson, R. C.	1958	L	298-1773		Expansion measurement calibrated with synthetic sapphire.
17*	457	Price, R. J.	1969	L	295, 1273		Pyrolytic β-silicon carbide: 0. 0087 Cr, 0. 006 Al, 0. 002 Cu, 0. 002 Fe, 0. 001 Ni, 0. 0008 Mg, 0. 0004 Mn: deposited in a fluidized bed between 1473 K and 2073 K from methytrichlorosilane-hydrogen mixture: strip approximately 0. 6 x 0. 1 x 0. 01 cm cut from the deposits; mean coefficient of expansion parallel to the deposition plane reported.

* Not shown in figure.

SPECIFICATION TABLE 250. THERMAL LINEAR EXPANSION OF SILICON CARBIDE SiC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
18*	246	Norton, F. H.	1925	O	293-1929	Silicon Carbide Brick	Brick made of pure SiC crystal fitted together at high temperature: no clay bonded used; specimen cut out of standard sized brick, 1 in. sq., 9 in. long. ends accurately ground before placing in gas fired furnace with neutral atmosphere. heating rate 100 C per hr; zero-point correction of -0.021%.
19	160	Schaake, H. F.	1969	X	4.2-300		Specimen from Martin Marietta Corp., produced by vapor deposition. jet milled to sub-micron size, pressed into copper sample holder; x-ray analysis showed only cubic structure: lattice constant reported at 299.6 K is 4.3597 Å; 4.3596 Å at 293.2 K determined by graphical interpolation.
20	82	Rossi, R. C.	1969	L	293, 1273		Specimen hot pressed at more than 4000 psi and 1773 K; 97.0% of theoretical density.
21	458	Chuang, K. C.	1966	L	302-1020		Filament specimen, 5.08 cm long x 0.102 cm diameter: zero-point correction of 0.001% determined by graphical extrapolation.
22	583	Pojur, A. F., Yates, B., and Kelly, B. T.	1972	I	331-766		Specimen in hemispherical form; diameter 1 mm wall thickness a few hundredths of a mm.
23*	583	Pojur, A. F., et al.	1972	I	320-780		Same as above specimen.
24	686	Tagomi, Y.	1968		293-1141	β-SiC	No details; expansion measured along a-axis.
25*	686	Tagomi, Y.	1968		273-1212	β-SiC	Above specimen; expansion measured along c-axis; zero-point correction -0.006% determined by graphical extrapolation.
26	687	Coppala, J.A. and Brandt, R.C.	1972		673-1473		0.25 x 0.25 x 2 in. hectangular bars; Rx-B specimen.
27	687	Coppala, J.A. and Brandt, R.C.	1972		673-1473		Similar to the above except Rx-C specimen.
28	688	Suzuki, H., Iseki, T., and Ito, M.	1973	X	293-1173	β-SiC	Pure graphite and semiconductor grade silicon heated to 1773 K for 3 hr in vacuum to form β-SiC; then heated to 1073 K and treated with HNO_3, Hf solution for 1 hr to remove unreacted graphite, silica and unreacted silicon metal, respectively; non irradiated specimen; zero-point correction -0.002% determined by graphical extrapolation; reported error 0.008%.
29	688	Suzuki, H., et al.	1973	X	293-1173	Irradiated β-SiC	The above specimen; radiated at 5.0×10^{19} neutrons/cm; zero-point correction is -0.373% determined by graphical extrapolation.
30	688	Suzuki, H., et al.	1973	X	293-1173	Irradiated β-SiC	The above specimen; radiated at 2.4×10^{19} neutrons/cm; zero-point correction is -0.211% determined by graphical extrapolation.
31	688	Suzuki, H., et al.	1973	X	293-1173	Irradiated β-SiC	The above specimen; radiated at 1.5×10^{19} neutrons/cm; zero-point correction is -0.119% determined by graphical extrapolation.
32	689	Frantsevich, I.N., Gnesin, G.G., Dyban, Yu.P., Gaiduchenko, A.K., Osuvitskii, E.I., and Ostroverkhov, Ostroverkhov, V.I.	1972		373-1373		No details given.
33	690	Clark, D. and Knight, D.	1965	X	32-1183	β-SiC	Lattice parameter reported at 39 K as 4.3595 Å; 4.3647 Å at 253 K determined by graphical interpolation.

* Not shown in figure.

DATA TABLE 250. THERMAL LINEAR EXPANSION OF SILICON CARBIDE SiC

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
298	0.002
573	0.106
873	0.249
1073	0.396
1473	0.566
1773	0.769
CURVE 2*	
293	0.000
298	0.002
573	0.101
873	0.272
1073	0.430
1473	0.601
1773	0.828
CURVE 3*	
293	0.000
298	0.003
573	0.140
873	0.296
1073	0.457
1473	0.649
1773	0.858
CURVE 4	
320	0.012
523	0.099
774	0.211
1023	0.345
1274	0.486
1522	0.644
1775	0.813
2023	1.000
CURVE 5*	
293	0.000
473	0.040
673	0.120
873	0.240
1073	0.340
1273	0.400
1273	0.400
1473	0.515
1673	0.620
1673	0.620
CURVE 6	
266	-0.013
1644	0.681
CURVE 7	
273	-0.006
373	0.026
473	0.071
573	0.118
673	0.164
773	0.206*
873	0.257*
973	0.307
1073	0.360
1173	0.409
1273	0.460
1373	0.509
1473	0.554
1573	0.589
1588	0.594
CURVE 8	
299	0.002*
521	0.078
803	0.183
1075	0.339*
1231	0.424
CURVE 9	
299	0.003*
835	0.215
1255	0.424
1635	0.657
CURVE 10	
293	0.000*
699	0.165
755	0.187
810	0.212
866	0.240
922	0.267
977	0.296
1033	0.322
1088	0.352
1144	0.382
1199	0.415
1255	0.445
1310	0.482
1366	0.520
1422	0.570
1477	0.590
1533	0.616
1588	0.668
1644	0.711
1699	0.755
CURVE 11	
293	0.000*
1273	0.392
1773	0.740
2273	1.158
CURVE 12	
293	0.00*
1125	0.47
1205	0.52
1285	0.57
1369	0.61
1453	0.66
1545	0.73
1717	0.78
1865	0.89
1957	0.95
2073	1.02
2185	1.08
2261	1.13
2301	1.16
2349	1.20
2413	1.22
2469	1.26
2517	1.29
2565	1.32
2633	1.36
2697	1.38
CURVE 13	
2697	1.38*
2669	1.40
2637	1.32
2485	1.22
2373	1.18
2229	1.09
2121	1.04
2009	0.96
1977	0.91
1909	0.89
1853	0.84
1769	0.82
1681	0.80
1593	0.75
1485	0.64
1385	0.64
1313	0.60
1213	0.56
1157	0.51
293	0.00*
CURVE 14	
299.8	0.003*
372.1	0.039
429.8	0.069
474.3	0.091
504.3	0.098
537.6	0.110
593.2	0.150
643.7	0.175
712.1	0.204
753.7	0.239
830.4	0.293
888.7	0.312
936.5	0.322
972.1	0.352
1024.8	0.371
1112.1	0.426
1160.9	0.441
1204.3	0.460
1276.5	0.514
1323.2	0.537
1370.9	0.554
1415.9	0.576
1463.7	0.601
1504.8	0.634
1559.7	0.643
1615.9	0.709
1679.3	0.745
1734.8	0.761
1778.2	0.788
1839.8	0.813
1879.3	0.845
CURVE 15*	
298	0.002
473	0.061
673	0.162
873	0.254
1073	0.356
1273	0.468
CURVE 16	
298	0.002*
473	0.059
673	0.154
873	0.249*
1073	0.352
1273	0.468
1473	0.592*
1673	0.718
1773	0.782*
CURVE 17*	
295	0.001
1273	0.480
CURVE 18*	
293	0.000
328	0.002
547	0.111
774	0.226
1062	0.331
1236	0.394
1543	0.511
1783	0.624
1929	0.682
CURVE 19	
4.2	-0.0160
4.2	-0.0252
20	-0.0229
40	-0.0252
60	-0.0206
77.4	-0.0252
77.4	-0.0183
100	-0.0229
120	-0.0252
140	-0.0206
155	-0.0206
170	-0.0229
194.6	-0.0160
215	-0.0137
235	-0.0091
255	-0.0068
273.2	-0.0022*
299.6	0.0022*
CURVE 20	
293	0.000*
1273	0.446
CURVE 21	
302	0.001*
329	0.004*
350	0.013
367	0.021*
401	0.030
429	0.035
447	0.045
464	0.048
486	0.052
497	0.056
514	0.065
552	0.077
591	0.092
618	0.104
640	0.114

* Not shown in figure.

DATA TABLE 250. THERMAL LINEAR EXPANSION OF SILICON CARBIDE SiC (continued)

T	$\Delta L/L_0$
CURVE 21 (cont.)	
701	0.137
773	0.162
820	0.175
843	0.185
873	0.206
896	0.221
961	0.246
978	0.252
998	0.269
1020	0.275
CURVE 22	
331	0.012
350	0.018
371	0.025*
390	0.031
410	0.038
434	0.047
455	0.055
474	0.062*
492	0.069
513	0.077
532	0.085
551	0.073
570	0.101*
590	0.110
619	0.122
640	0.132
662	0.142
685	0.152
707	0.161
728	0.170
746	0.178
766	0.187
CURVE 23*	
320	0.008
340	0.014
360	0.020
380	0.027
400	0.034
420	0.041
440	0.048
460	0.056
480	0.064
500	0.072
520	0.080

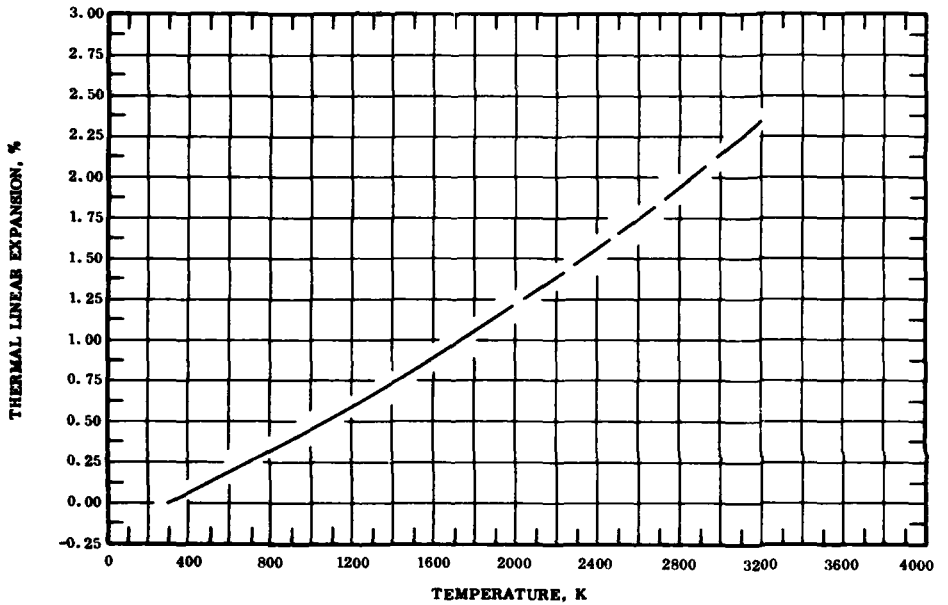
T	$\Delta L/L_0$
CURVE 23 (cont.)*	
540	0.088
560	0.096
580	0.103
600	0.113
620	0.122
640	0.131
660	0.139
680	0.148
700	0.157
720	0.166
740	0.175
760	0.183
780	0.192
CURVE 24	
293	0.000*
323	0.007*
373	0.015
423	0.028*
473	0.044*
523	0.059
573	0.078
623	0.099
673	0.117*
723	0.140
773	0.162*
823	0.186
873	0.210
923	0.235
973	0.260
1023	0.290
1073	0.317
1123	0.345
1141	0.355
CURVE 25*	
273	-0.006
293	0.000
323	0.007
373	0.019
423	0.031
433	0.035
473	0.039
490	0.054
523	0.064
573	0.070
623	0.091

T	$\Delta L/L_0$
CURVE 25 (cont.)*	
673	0.113
723	0.139
773	0.163
823	0.196
873	0.222
923	0.248
973	0.270
1023	0.295
1073	0.321
1123	0.344
1173	0.367
1212	0.387
CURVE 26	
673	0.168*
1473	0.504
CURVE 27	
673	0.144
1473	0.432
CURVE 28	
293	0.000*
573	0.091
773	0.180
973	0.271
1173	0.383
CURVE 29	
293	0.000*
573	0.089*
773	0.160*
973	0.153
1173	0.163
CURVE 30	
293	0.000*
573	0.091*
673	0.136
773	0.181*
823	0.194
873	0.206
973	0.213
1173	0.263

T	$\Delta L/L_0$
CURVE 31	
293	0.000*
393	0.035
503	0.070
544	0.083
573	0.091*
617	0.114
673	0.135*
773	0.165
973	0.230
1173	0.301
CURVE 32	
373	0.020*
1373	0.396
CURVE 33	
32	-0.119
695	0.183
1014	0.339
1183	0.410

* Not shown in figure.

FIGURE AND TABLE NO. 251R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF TANTALUM CARBIDE TaC



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	5.6
300	0.004	5.6
400	0.063	5.8
500	0.122	6.0
600	0.184	6.2
700	0.246	6.3
800	0.310	6.5
900	0.376	6.6
1000	0.443	6.8
1200	0.583	7.1
1400	0.728	7.4
1600	0.881	7.8
1800	1.039	8.1
2000	1.205	8.4
2200	1.378†	8.8
2400	1.557†	9.2
2600	1.744†	9.5
2800	1.938†	9.9
3000	2.140†	10.3
3200	2.349†	10.7

† Provisional values.

REMARKS

The recommended values are based on the data for pure samples and are based on the most recent measurements. No weight was given in the analysis to curves 14 and 16. The recommended values are considered accurate to within ± 5% at temperatures below 2000 K and to within ± 7% above 2000 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.162 + 5.324 \times 10^{-4} T + 6.990 \times 10^{-8} T^2 + 2.780 \times 10^{-12} T^3$$

The values of the coefficient of thermal expanion are primarily calculated by differentiating the above equation and are considered accurate to about ± 7%.

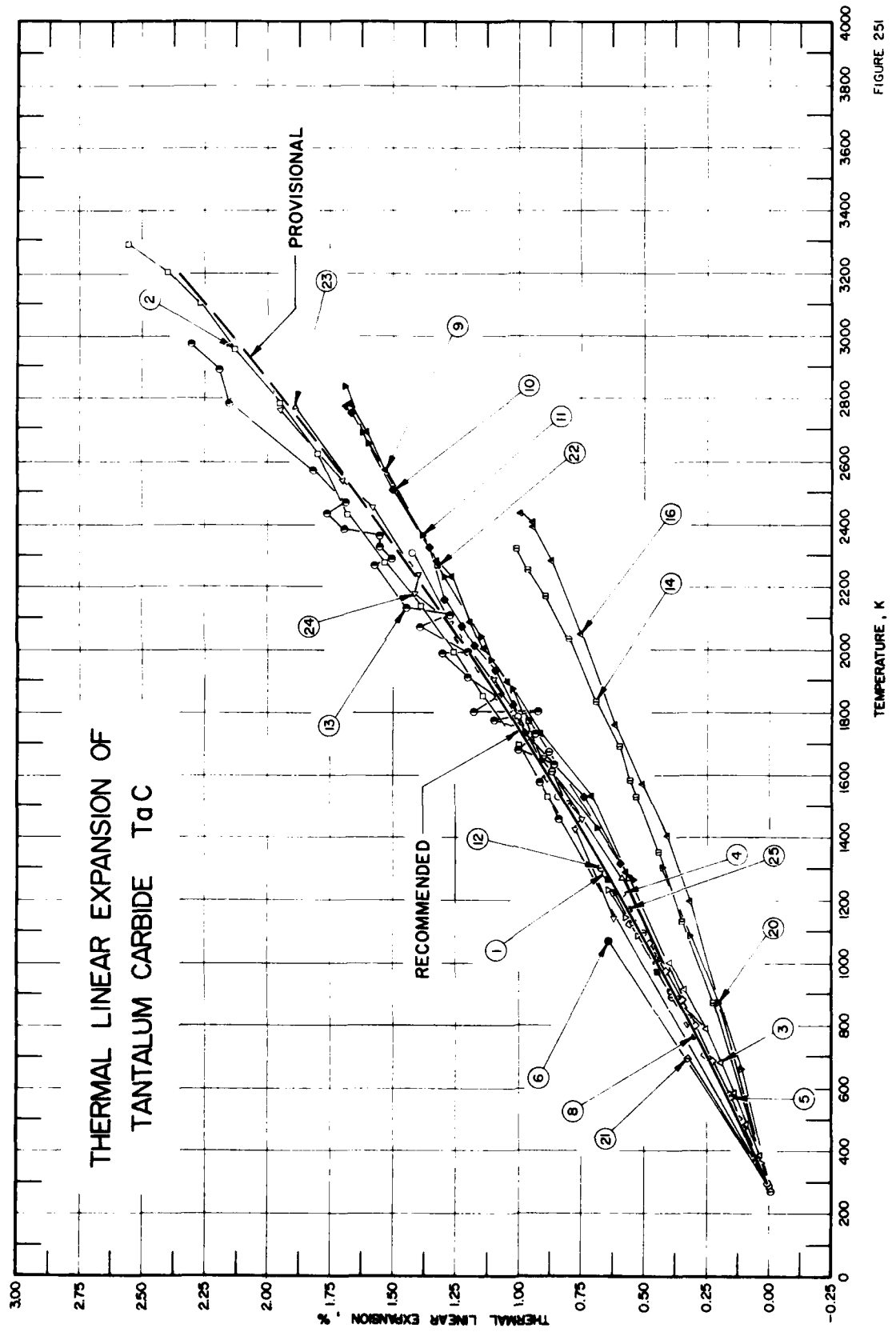

THERMAL LINEAR EXPANSION OF
TANTALUM CARBIDE TaC
PROVISIONAL
RECOMMENDED
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000

FIGURE 251

SPECIFICATION TABLE 251. THERMAL LINEAR EXPANSION OF TANTALUM CARBIDE TaC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	438	Houska, C. R.	1963	X	298-2317	$TaC_{1.02}$	93.81 Ta, 6.35 combined carbon, 0.1 Zr, 0.05 Cb, 0.02 Fe, 0.02 O, 0.01 Cr, and 0.01 Ti; sample made by reacting tantalum with carbon at about 2573 K for 3 hr: cold pressed at 14 000 psi, using camphor, sintered in vacuum at about 2073 K for 1 hr; data obtained from (422) and (511/333) by using CuKα radiation; reported error < 2%: zero-point correction of 0.003% determined by graphical extrapolation.
2	444	Kempter, C. P. and Nadler, M. R.	1965	D	294-3293	$TaC_{0.97}$	93.8 Ta + Nb, 6.29 total carbon, > 1 Nb, 0.45-0.455 O, and 0.1 free carbon: rod prepared by the LASL powder metallurgy section from Fansteel Metallurgical Corp.; tantalum carbide powder, formed by hydrostatic pressing at 30 000 psi and fired at 2773 K in coarse graphite for 3 hr: finished (with fiducial marks ~2.750 in. apart) to 0.25 in. diameter: no evidence of a high-temperature phase change found.
3	445	Fries, R. J. and Wahman, L. A.	1967	X	298-1001	$TaC_{0.789}$	93.9 Ta, 4.92 combined C, <0.050 free C, 0.045 O, and 0.003 N; carbide prepared by heating cylindrical plug that cold-pressed from mixture of powdered elements to 2073 K in helium atmosphere for 30 min.: ground to -200 mesh, remixed, and reheated several times: hot HCl leach used: holding sample at 2273 K in vacuum of about 2×10^{-6} torr for 12-18 hr: lattice parameter reported at 298.2 K is 4.4243 Å; 4.4242 Å at 293.2 K determined by graphical extrapolation.
4	445	Fries, R. J. and Wahman, L. A.	1967	X	298-1222	$TaC_{0.912}$	Similar to the above specimen except 94.1 Ta, 5.70 combined C, 0.050 free C, 0.015 O, and 0.007 N; lattice parameter reported at 298.2 K is 4.4430 Å; 4.4429 Å at 293.2 K determined by graphical extrapolation.
5	445	Fries, R. J. and Wahman, L. A.	1967	X	298-1236	$TaC_{0.997}$	Similar to the above specimen except 92.3 Ta, 6.11 combined C, 0.96 free C, 0.020 O, and < 0.001 N; lattice parameter reported at 298.2 K is 4.4562 Å; 4.4561 Å at 293.2 K determined by graphical extrapolation.
6	69	Finlay, G. R.	1952		293, 1073		Specimen density 14.65 g cm^{-3}.
7*	423	Brizes, W. F.	1968	T	783-2324		High purity Ta rod inserted into graphite mold: diffusion annealed at ~ 473 K below carbide-carbon eutectic temperature: m.p., 4273 K: expansion measured in 15 μ helium atmosphere: this curve is here reported using the first given temperature (783 K) as reference temperature at which $\Delta L/L_0 = 0$.
8	424	Elliott, R. O. and Kempter, C. P.	1958	X	296-1267		99.5 pure, 0.05 free carbon: specimen obtained from D. H. Sebell at Los Alamos Scientific Laboratories. 325 mesh sample sealed in silica capillary: lattice constant reported at 296.2 K is 4.4540 Å; 4.4539 Å at 293.2 K determined by graphical extrapolation.
9	425	Miccioli, B. R. and Shaffer, P. T. B.	1964	T	1291-2782		Expansion measured on run 1.
10	425	Miccioli, B. R. and Shaffer, P. T. B.	1964	T	1320-2752		Expansion measured on run 2.
11	425	Miccioli, B. R. and Shaffer, P. T. B.	1964	T	1263-2840		Expansion measured on run 3.
12	10	Mauer, F. A. and Bolz, L. H.	1955		273-1673		98.5+ pure, < 1.0 Nb, < 0.1 Al, < 0.01 any other element: commercial powder sintered at 1473 K: expansion measured in helium atmosphere: zero-point correction of -0.012% determined by graphical interpolation.
13	426	Paderno, Yu. B.	1965	T	918-2976		99.96 pure: hot pressed specimen, 15-18 mm long, 8 mm diameter: expansion measured in atmosphere of 10^{-2} mm Hg pressure.

* Not shown in figure.

SPECIFICATION TABLE 251. THERMAL LINEAR EXPANSION OF TANTALUM CARBIDE TaC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
14	318	Neel, D.S., Pears, C.D. and Oglesby, S., Jr.	1962	L	293-2322		Before exposure 93.8 Ta, 6.77 C, < 0.1 N, elements found by semi-quantitative emission spectrography 0.1 Fe and 0.1 Si: after exposure 93.8 Ta, 6.52 C, and < 0.1 N; initial and final length 3.0010 in.: Kenametal, Inc.; hot pressed: run SRI-E7; density g cm^{-3} at 298 K before exposure 14.0 by ASTM method B311-58 and 14.1 by wax-coating specimen and by immersion in xylene, after exposure 13.8 by wax-coating specimen and 13.9 by ASTM method and by immersion in xylene; expansion measured in helium atmosphere; reported error 2%.
15	318	Neel, D.S., et al.	1962	L	2322-293		The above specimen: expansion measured with decreasing temperature: zero-point correction of -0.02%.
16	318	Neel, D.S., et al.	1962	L	293-2438		The above specimen: initial length 3.0020 in., final length 3.0040 in.: run SRI-E16: expansion measured with increasing temperature on second test.
17*	318	Neel, D.S., et al.	1962	L	2438, 293		The above specimen: expansion measured with decreasing temperature: zero-point correction of -0.47%.
18	318	Neel, D.S., et al.	1962	L	293-2844		The above specimen: initial length 3.0040 in., final length 3.0179 in.: run SRI-E7: expansion measured with increasing temperature on third test.
19*	318	Neel, D.S., et al.	1962	L	2844, 293		The above specimen: expansion measured with decreasing temperature: zero-point correction of -0.47%.
20	439	Nowotny, H.	1961	X	293-1303		Specimen of almost stoichiometric composition.
21	446	Panov, V.S. and Meerson, G.A.	1968	L	291, 693		Hot pressed specimen, 16 mm diameter by 5 to 10 mm high, annealed at 1723 K for 48 hr.
22	432	Miccioli, B.R. and Julien, H.P.	1965	T	300-2773		Hot pressed specimen, density 12.81 g cm^{-3}: expansion measured perpendicular to pressing direction.
23	432	Miccioli, B.R. and Julien, H.P.	1965	T	300-2773		Similar to the above specimen, density 13.44 g cm^{-3}: expansion measured parallel to pressing direction.
24	657	Jun, C.K. and Shaffer, P.T.B.	1971	T	293-2766		93.5 Ta, 6.16 C (combined), 0.08 Nb, W, 0.06 C (free), 0.02 Cr, 0.015 Fe, 0.01 N, Ti; dimensions 0.125 in. x 0.125 in. x 2.8 in. cut from a cylinder 3 in. O.D. x 3 in. long which was hot pressed at 3100-3150 C: measurements obtained in argon atmosphere; zero-point correction is 0.009% at 293 K.
25*	658	Ridley, N. and Stuart, H.	1970	X	273-1289		93.1 Ta, 6.12 C (total), 0.3 O, 0.05 N, < 0.05 C (free), < 0.05 each Fe, Nb, W, < 0.01 each Cr, Ni, Ti; powdered specimen placed in 0.05 mm diameter quartz capillary tube ~4 cm long.
26*	659	Bortz, S.A.	1968		293, 2593		73.7 Ta, 26.3 C; particle sizes for coke and Ta was 15 μ; specimen formed by hot pressing of binary mixtures of carbon and metal or metal carbide at 3223 to 3523 K; the carbon was needle petroleum coke having needle-like particle; expansion measured across grain.
27*	659	Bortz, S.A.	1968		293, 2593		The above specimen except expansion measured with grain.

* Not shown in figure.

SPECIFICATION TABLE 251. THERMAL LINEAR EXPANSION OF TANTALUM CARBIDE TaC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
28*	660	Samsonov, G.V. and Navmenko, V.Ya.	1969	L	298, 1273		93.44 Ta, 6.22 C (total); made by sintering process at 160 kg/cm^2 at 2373-2873 K for 15 min; cut from 8 x 12-15 mm rod into 2.5 x 2.5 x 12-14 mm bar; annealed at 2273-2473 K for 8 hr at 1.2 x 10^{-4} mm Hg; expansion measured in argon atmosphere.
29*	660	Samsonov, G.V. and Navmenko, V.Ya.	1969	L	298, 1273	$TaC_{0.91}$	Similar to the above specimen except 93.95 Ta and 5.62 C (total).
30*	660	Samsonov, G.V. and Navmenko, V.Ya.	1969	L	298, 1273	$TaC_{0.85}$	Similar to the above specimen except 94.15 Ta and 5.34 C (total).
31*		Samsonov, G.V. and Navmenko, V.Ya.	1969	L	298, 1273	$TaC_{0.82}$	Similar to the above specimen except 94.32 Ta and 5.21 C (total).
32*	60	Samsonov, G.V. and Navmenko, V.Ya.	1969	L	298, 1273	$TaC_{0.73}$	Similar to the above specimen except 94.87 Ta and 4.54 C (total).
33*	99	Samsonov, G.V., Grebenkina, V.G., and Klimenko, V.S.	1971	L	293-1293		Reported error 1.5%; 3 x 3 x 15 mm rectangular bar; zero-point correction is 0.031% at 293 K.

* Not shown in figure.

DATA TABLE 251. THERMAL NEAR EXPANSION OF TANTALUM CARBIDE TaC

[Temperature, T, K; Linear Expansion, $\Delta L / L_0$, %]

CURVE 1

T	$\Delta L / L_0$
298	0.003
1027	0.467
1284	0.653
1534	0.840
1787	1.003
2041	1.233
2317	1.423

CURVE 2

T	$\Delta L / L_0$
294	0.00
1532	0.88
1698	1.00
1853	1.14
1996	1.26
2140	1.38
2280	1.53
2430	1.68
2622	1.80
2784	1.95
2957	2.13
3105	2.27
3205	2.40
3[illegible]	2.56

CURVE 3

T	$\Delta L / L_0$
298	0.002*
382	0.036
487	0.088
584	0.140
681	0.194
790	0.253
918	0.336
1001	0.393

CURVE 4

T	$\Delta L / L_0$
298	0.002*
378	0.047
502	0.121
581	0.159
690	0.229
804	0.299
883	0.346
979	0.416

CURVE 4 (cont.)

T	$\Delta L / L_0$
1061	0.479
1172	0.551
1222	0.587

CURVE 5

T	$\Delta L / L_0$
298	0.002
364	0.029
474	0.103
573	0.154
696	0.237
827	0.323
891	0.370
1004	0.455
1087	0.525
1149	0.570
1236	0.637

CURVE 6

T	$\Delta L / L_0$
293	0.00*
1073	0.64

CURVE 7*, †, ‡

T	$\Delta L / L_0$
783	0.00
1047	0.18
1161	0.25
1492	0.48
1823	0.71
2324	1.05

CURVE 8

T	$\Delta L / L_0$
296	0.002*
771	0.300
978	0.446
1267	0.646

CURVE 9

T	$\Delta L / L_0$
1291	0.572
1536	0.707
1731	0.913
1900	1.048
2005	1.141

CURVE 9 (cont.)

T	$\Delta L / L_0$
2094	1.191
2239	1.268
2283	1.326
2577	1.533
2697	1.613
2782	1.676

CURVE 10

T	$\Delta L / L_0$
1320	0.592
1532	0.737
1735	0.974
1825	1.025
1935	1.093
2014	1.179
2078	1.225
2160	1.290
2327	1.358
2510	1.500
2752	1.666

CURVE 11

T	$\Delta L / L_0$
1263	0.543
1435	0.680
1648	0.908
1874	1.025
1968	1.113
2043	1.149
2235	1.294
2366	1.379
2658	1.599
2686	1.616
2840	1.686

CURVE 12

T	$\Delta L / L_0$
273	-0.012
300	0.004*
479	0.102*
685	0.244*
891	0.383
1097	0.509
1303	0.675
1509	0.807
1613	0.868

CURVE 12 (cont.)

T	$\Delta L / L_0$
1673	0.875

CURVE 13

T	$\Delta L / L_0$
918	0.394
1129	0.541
1273	0.637*
1460	0.838
1581	0.918
1634	0.860
1680	1.001
1728	0.929
1779	1.099
1802	0.922
1802	1.177
1851	1.083
1917	1.201
1986	1.303
1992	1.206
2074	1.388
2110	1.273
2136	1.444
2273	1.572
2294	1.502
2330	1.551
2364	1.551
2383	1.694
2433	1.766
2467	1.689
2571	1.821
2782	2.160
2893	2.196
2976	2.305

CURVE 14

T	$\Delta L / L_0$
293	0.00*
877	0.25
1138	0.35
1355	0.44
1533	0.53
1583	0.56
1694	0.60
1833	0.69
2033	0.80
2172	0.89

CURVE 14 (cont.)

T	$\Delta L / L_0$
2255	0.97
2322	1.01

CURVE 15*

T	$\Delta L / L_0$
2322	0.99
2277	1.02
2210	0.94
2110	1.01
1994	1.00
293	0.00

CURVE 16

T	$\Delta L / L_0$
293	0.00*
1199	0.32
1405	0.41
1577	0.51
1760	0.62
2049	0.75
2283	0.87
2394	0.94
2405	0.94
2438	0.99

CURVE 17*

T	$\Delta L / L_0$
2438	0.52
293	0.00

CURVE 18*

T	$\Delta L / L_0$
293	0.00
1522	0.62
1941	0.86
2358	1.13
2449	1.18
2547	1.23
2616	1.28
2716	1.37
2797	1.49
2841	1.59
2838	1.63
2844	1.75
2844	1.77

CURVE 19*

T	$\Delta L / L_0$
2844	1.30
293	0.00

CURVE 20

T	$\Delta L / L_0$
293	0.000*
663	0.112
873	0.202
1088	0.315
1303	0.427

CURVE 21

T	$\Delta L / L_0$
291	-0.002*
693	0.326

CURVE 22

T	$\Delta L / L_0$
300	0.004*
1273	0.563
1773	0.965
2273	1.323
2773	1.689

CURVE 23

T	$\Delta L / L_0$
300	0.004*
1273	0.581
1773	1.006
2273	1.431
2773	1.897

CURVE 24

T	$\Delta L / L_0$
293	0.000*
1143	0.619
1426	0.775
1466	0.756
1584	0.888
1656	0.897
1780	0.965*
1785	1.007*
1908	1.108
1941	1.164
2035	1.245
2085	1.269

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L / L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L / L_0$.

DATA TABLE 251. THERMAL LINEAR EXPANSION OF TANTALUM CARBIDE TaC (continued)

T	$\Delta L/L_0$
CURVE 24 (cont.)	
2180	1.412
2240	1.405
2397	1.568*
2456	1.581
2539	1.702
2766	1.947
CURVE 25	
293	0.000*
507	0.115*
714	0.256
809	0.326
917	0.389*
1002	0.451*
1089	0.508*
1168	0.561
1222	0.618
CURVE 26*	
293	0.000
2593	2.799
CURVE 27*	
293	0.000
2593	1.771
CURVE 28*	
293	0.004
1273	0.709
CURVE 29*	
298	0.003
1273	0.699
CURVE 30*	
298	0.003
1273	0.696
CURVE 31*	
298	0.003
1273	0.698
CURVE 32*	
298	0.004
1273	0.710
CURVE 33*	
293	0.000
473	0.117
528	0.160
CURVE 33 (cont.)*	
583	0.199
639	0.2[illegible]
689	0.277
744	0.318
801	0.358
849	0.398
907	0.435
963	0.478
1013	0.516
1064	0.557
1120	0.596
1178	0.646
1232	0.677
1285	0.714

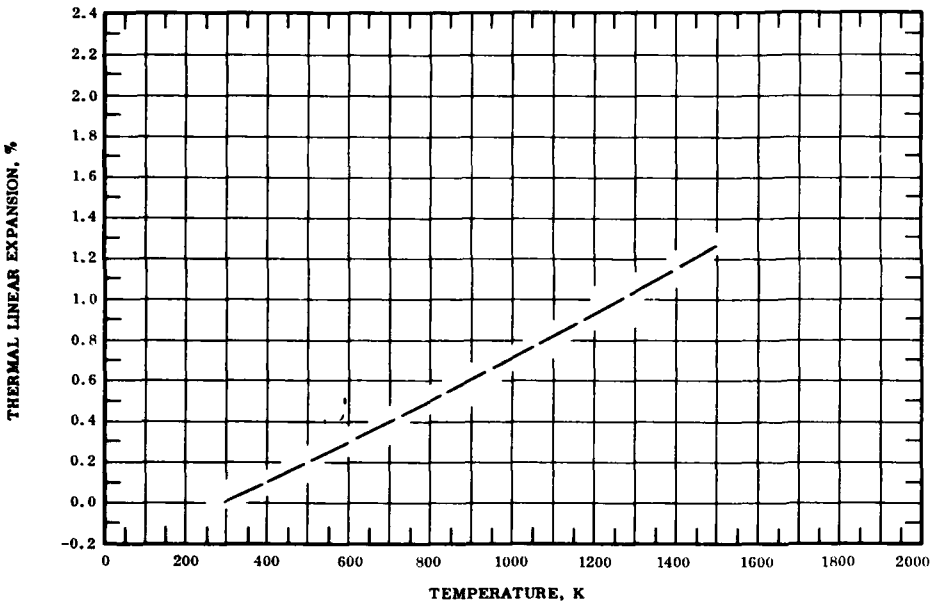
DATA TABLE 251. COEFFICIENT OF THERMAL LINEAR EXPANSION OF TANTALUM CARBIDE TaC

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 7*,‡	
783	6.57
1047	6.86
1161	6.68
1492	7.04
1823	6.72
2324	6.97

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 252R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF THORIUM DICARBIDE ThC_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	8.9
300	0.006	9.0
400	0.101	9.5
500	0.198	9.8
600	0.297	10.1
700	0.399	10.3
800	0.502	10.5
900	0.608	10.6
1000	0.715	10.8
1100	0.823	10.9
1200	0.933	11.0
1300	1.043	11.0
1400	1.154	11.1
1500	1.266	11.2

REMARKS

The provisional values are based on the results of curves 1 and 21 below the transition point. The data represented by curves 2-19 (by the same authors), show a considerable scatter as a result of repeated heating/cooling cycles, thus indicating sample instability. The provisional values are considered accurate to about ± 10% and are represented approximately by the following equation. No evaluation can be made beyond the transition point.

$$\Delta L/L_0 = -0.257 + 8.277 \times 10^{-4}\ T + 1.829 \times 10^{-7}\ T^2 - 3.863 \times 10^{-11}\ T^3$$

The tabulated values of the coefficient of thermal expansion are calculated by differentiating the above equation and are considered accurate to about ± 7%.

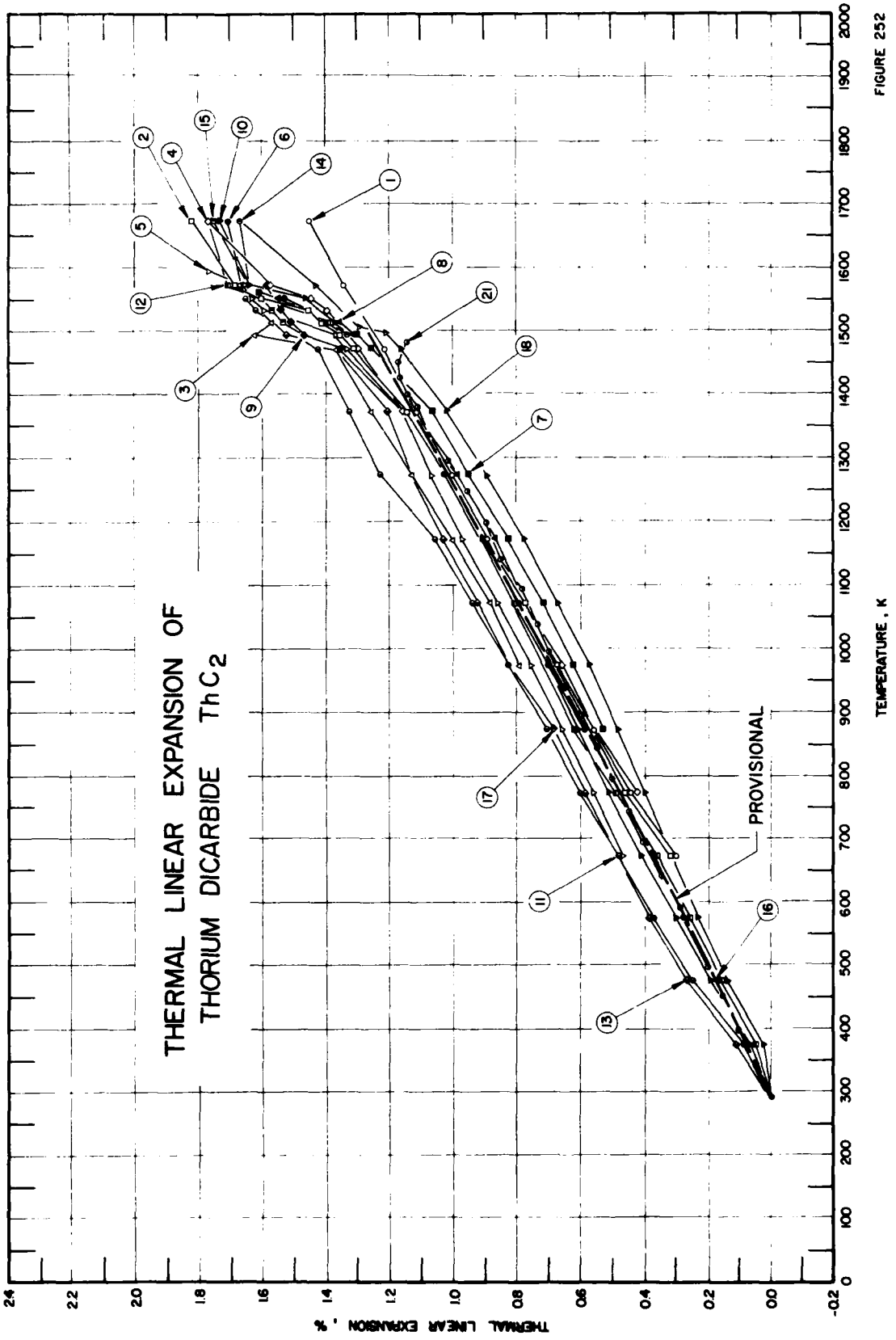

THERMAL LINEAR EXPANSION OF
THORIUM DICARBIDE ThC_2
PROVISIONAL
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
24
22
20
18
16
14
12
10
08
06
04
02
00
-02
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 252

SPECIFICATION TABLE 252. THERMAL LINEAR EXPANSION OF THORIUM DICARBIDE ThC_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	441	Marchal, M., Accary, A. and Saclay, C. E. A.	1963	O	673-1673	No. 503	Specimen sintered 4 hr at 2073 K; density 8.9 g cm^{-3}.
2	441	Marchal, M., et al.	1963	O	673-1673	No. B-1	Electron beam melted specimen; expansion measured with heating rate 150 C per hr.
3	441	Marchal, M., et al.	1963	O	1573-973	No. B-1	The above specimen; expansion measured with decreasing temperature.
4	441	Marchal, M., et al.	1963	O	673-1673	No. B-1	The above specimen; expansion measured with increasing temperature on second thermal cycle.
5	441	Marchal, M., et al.	1963	O	1593-673	No. B-1	The above specimen; expansion measured with decreasing temperature on second thermal cycle.
6	441	Marchal, M., et al.	1963	O	873-1673	No. B-1	The above specimen; expansion measured with increasing temperature on third thermal cycle.
7	441	Marchal, M., et al.	1963	O	1673-873	No. B-1	The above specimen; expansion measured with decreasing temperature on third thermal cycle.
8	441	Marchal, M., et al.	1963	O	973-1673	No. B-1	The above specimen; expansion measured with increasing temperature on fourth thermal cycle.
9	441	Marchal, M., et al.	1963	O	1673-973	No. B-1	The above specimen; expansion measured with decreasing temperature on fourth thermal cycle.
10	441	Marchal, M., et al.	1963	O	373-1673	No. B-2	Similar to the above specimen; expansion measured with increasing temperature.
11	441	Marchal, M., et al.	1963	O	1673-373	No. B-2	The above specimen; expansion measured with decreasing temperature.
12	441	Marchal, M., et al.	1963	O	373-1673	No. B-2	The above specimen; expansion measured with increasing temperature on second thermal cycle.
13	441	Marchal, M., et al.	1963	O	1673-373	No. B-2	The above specimen; expansion measured with decreasing temperature on second thermal cycle.
14	441	Marchal, M., et al.	1963	O	373-1673	No. B-2	The above specimen; expansion measured with increasing temperature on third thermal cycle.
15	441	Marchal, M., et al.	1963	O	1673-473	No. B-2	The above specimen; expansion measured with decreasing temperature on third thermal cycle.
16	441	Marchal, M., et al.	1963	O	373-1673	No. B-2	The above specimen; expansion measured with increasing temperature on fourth thermal cycle.
17	441	Marchal, M., et al.	1963	O	373-1673	No. B-4	Similar to the above specimen; expansion measured with increasing temperature.
18	441	Marchal, M., et al.	1963	O	373-1673	No. B-4	The above specimen; expansion measured with increasing temperature on second thermal cycle.
19*	441	Marchal, M., et al.	1963	O	1673-373	No. B-4	The above specimen; expansion measured with decreasing temperature on second thermal cycle.
20*	656	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	373, 1173		No details given.
21	655	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	293-1482		Zero-point correction of 0.074% determined by graphical interpolation.

* Not shown in figure.

DATA TABLE 252. THERMAL LINEAR EXPANSION OF THORIUM DICARBIDE ThC_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
673	0.307
773	0.445
873	0.562
973	0.675
1073	0.796
1173	0.897
1273	1.008
1373	1.125
1473	1.217
1573	1.347
1673	1.452

CURVE 2

T	$\Delta L/L_0$
673	0.323
773	0.464
873	0.564*
973	0.673*
1073	0.774
1173	0.887*
1273	1.014*
1373	1.147
1473	1.317
1493	1.358
1513	1.412
1533	1.456
1553	1.602
1573	1.684
1673	1.825

CURVE 3

T	$\Delta L/L_0$
1573	1.677
1513	1.570
1493	1.627
1473	1.367
1373	1.257
1273	1.135
1173	1.002
1073	0.889
973	0.792

CURVE 4

T	$\Delta L/L_0$
673	0.303*
773	0.430

CURVE 4 (cont.)

T	$\Delta L/L_0$
873	0.556*
973	0.663
1073	0.779*
1173	0.889*
1273	1.019*
1373	1.159
1473	1.300
1533	1.399
1553	1.444
1573	1.579
1673	1.769

CURVE 5

T	$\Delta L/L_0$
1593	1.769
1573	1.658
1553	1.637
1533	1.597
1513	1.409*
1493	1.366
1473	1.339
1373	1.168*
1273	1.077
1173	0.970
1073	0.860
973	0.757
873	0.660
773	0.562
673	0.473

CURVE 6

T	$\Delta L/L_0$
873	0.590
973	0.706
1073	0.800*
1173	0.906*
1273	1.030
1373	1.156*
1473	1.323*
1493	1.375*
1513	1.414*
1533	1.455*
1553	1.537
1573	1.676*
1673	1.710

CURVE 7

T	$\Delta L/L_0$
1673	1.749*
1573	1.653*
1553	1.613
1533	1.562*
1513	1.509*
1493	1.297
1473	1.259
1373	1.070
1273	0.951
1173	0.829
1073	0.725
973	0.628
873	0.537

CURVE 8

T	$\Delta L/L_0$
973	0.674*
1073	0.768*
1173	0.868
1273	0.990
1373	1.130*
1473	1.305*
1493	1.315
1513	1.360
1533	1.399*
1553	1.557
1573	1.598*
1673	1.699*

CURVE 9

T	$\Delta L/L_0$
1673	1.692*
1573	1.591
1553	1.578*
1533	1.543
1513	1.512
1493	1.468
1473	1.359
1373	1.146*
1273	1.007*
1173	0.877*
1073	0.771*
973	0.674*

CURVE 10

T	$\Delta L/L_0$
373	0.071
473	0.198
573	0.305
673	0.415
773	0.516
873	0.610
973	0.700*
1073	0.794*
1173	0.904*
1273	1.023*
1373	1.146*
1473	1.293*
1493	1.321*
1513	1.369
1533	1.406*
1553	1.465
1573	1.648
1673	1.740

CURVE 11

T	$\Delta L/L_0$
1673	1.733*
1573	1.684*
1553	1.656
1533	1.623
1513	1.570*
1493	1.467*
1473	1.423
1373	1.328
1273	1.228
1173	1.060
1073	0.945
973	0.825
873	0.713
773	0.602
673	0.484
573	0.378
473	0.257
373	0.090

CURVE 12

T	$\Delta L/L_0$
373	0.058
473	0.160
573	0.260
673	0.362

CURVE 12 (cont.)

T	$\Delta L/L_0$
773	0.498
873	0.620
973	0.716*
1073	0.807
1173	0.908
1273	1.027*
1373	1.159*
1473	1.322*
1493	1.360*
1513	1.399
1533	1.445*
1553	1.656*
1573	1.711
1673	1.772*

CURVE 13

T	$\Delta L/L_0$
1673	1.772*
1573	1.677*
1553	1.650*
1533	1.610*
1513	1.571*
1493	1.530
1473	1.346*
1373	1.205
1273	1.138*
1173	1.038
1073	0.933
973	0.819*
873	0.709*
773	0.595
673	0.498*
573	0.385
473	0.270
373	0.117

CURVE 14

T	$\Delta L/L_0$
373	0.064*
473	0.165*
573	0.282
673	0.387
773	0.506*
873	0.615*
973	0.715*
1073	0.802*

CURVE 14 (cont.)

T	$\Delta L/L_0$
1173	0.908*
1273	1.025*
1373	1.150*
1473	1.310*
1493	1.333
1513	1.385*
1533	1.437
1553	1.457*
1573	1.655*
1673	1.672

CURVE 15

T	$\Delta L/L_0$
1673	1.755
1573	1.635*
1553	1.610*
1533	1.570
1513	1.540
1493	1.475*
1473	1.376*
1373	1.296
1273	1.172
1173	1.045*
1073	0.930*
973	0.819*
873	0.715*
773	0.600*
673	0.492*
573	0.380*
473	0.270*

CURVE 16

T	$\Delta L/L_0$
373	0.070*
473	0.180
573	0.280*
673	0.377*
773	0.515*
873	0.607*
973	0.700*
1073	0.795*
1173	0.910*
1273	1.027*
1373	1.160*
1473	1.308*
1493	1.335*

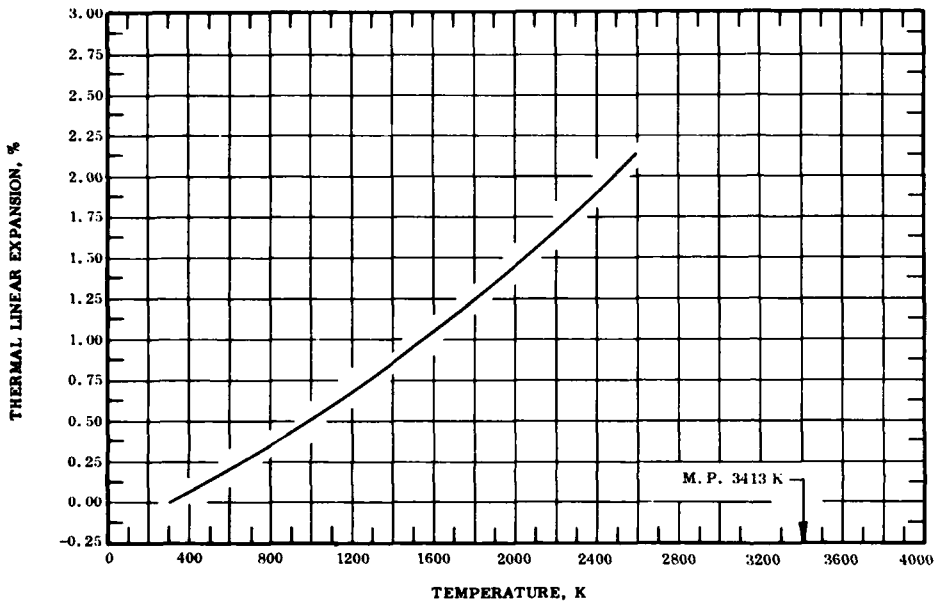
* Not shown in figure.

DATA TABLE 252. THERMAL LINEAR EXPANSION OF THORIUM DICARBIDE ThC_2 (continued)

T	$\Delta L/L_0$
CURVE 16 (cont.)	
1513	1.358*
1533	1.400*
1553	1.455*
1573	1.662*
1673	1.712*
CURVE 17	
373	0.092*
473	0.199*
573	0.305*
673	0.412*
773	0.522*
873	0.690
973	0.705*
1073	0.792*
1173	0.907*
1273	1.027*
1373	1.148*
1473	1.297*
1493	1.326*
1513	1.390*
1573	1.650*
1673	1.745*
CURVE 18	
373	0.029
473	0.142
573	0.233
673	0.321*
773	0.400
873	0.488
973	0.578
1073	0.672
1173	0.779
1273	0.896
1373	1.021
1473	1.166
1493	1.211
1513	1.296
1573	1.432
1673	1.668*
CURVE 19*	
1673	1.642
1573	1.541
1553	1.505
1533	1.400
1513	1.340
1473	1.260
1373	1.125
1273	0.989
1173	0.868
1073	0.761
973	0.662
873	0.570
773	0.478
673	0.386
573	0.292
473	0.206
373	0.113
CURVE 20*	
373	0.107
1173	0.963
CURVE 21	
293	0.000
398	0.109
452	0.160
493	0.204
590	0.293
642	0.353
694	0.412
744	0.455
795	0.503
843	0.557
894	0.601
940	0.654
994	0.706
1038	0.742
1094	0.784
1141	0.854
1197	0.901
1248	0.959
1293	1.020
1337	1.086
1379	1.122
1398	1.149
1424	1.171
1450	1.179
1482	1.155

* Not shown in figure.

FIGURE AND TABLE NO. 253R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF TITANIUM CARBIDE TiC



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	6.4
300	0.004	6.4
400	0.070	6.7
500	0.138	6.9
600	0.208	7.1
700	0.281	7.4
800	0.356	7.6
900	0.433	7.9
1000	0.513	8.1
1200	0.681	8.6
1400	0.859	9.1
1600	1.046	9.7
1800	1.245	10.2
2000	1.453	10.7
2200	1.672	11.2
2400	1.902	11.8
2600	2.143	12.3

REMARKS

The recommended values are based on the data for pure samples from the most recent measurements (curves 1, 3, and 25). These values are considered accurate to within ± 5%. These are represented approximately by the following equation:

$$\Delta L/L_0 = -0.177 + 5.710 \times 10^{-4}\, T + 1.174 \times 10^{-7}\, T^2 + 2.412 \times 10^{-12}\, T^3$$

The tabulated values of the coefficient of thermal expansion are primarily obtained by differentiating of the above equation. These values are considered accurate to about ± 7%.

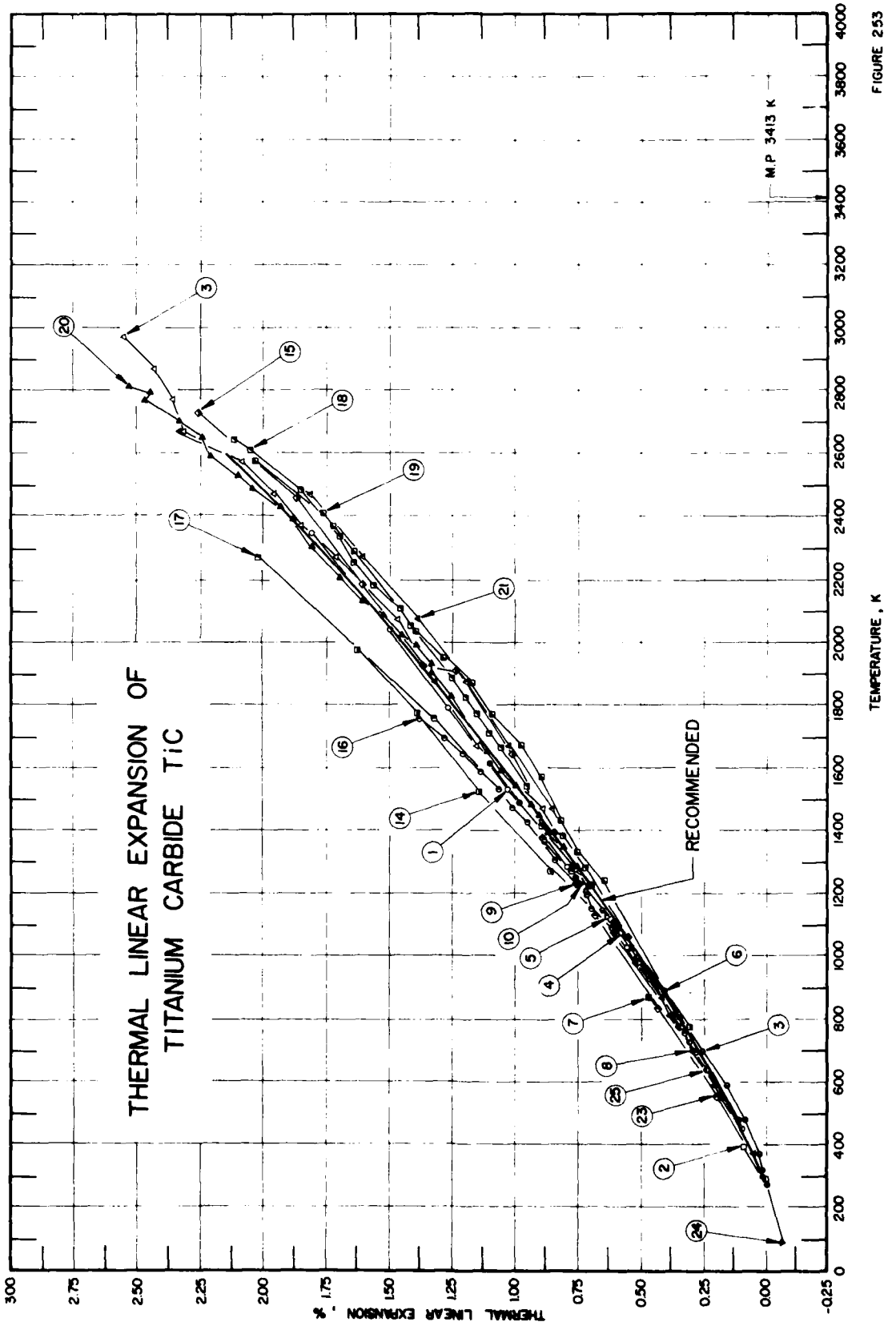

THERMAL LINEAR EXPANSION OF
TITANIUM CARBIDE TiC
RECOMMENDED
M.P 3413 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000

FIGURE 253

SPECIFICATION TABLE 253. THERMAL LINEAR EXPANSION OF TITANIUM CARBIDE TiC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	420	Houska, C. R.	1963	X	298-2353		79.35 Ti, 18.10 combined carbon, 0.67 N, 0.15 free carbon, 0.1 Fe, 0.035 O, and 0.021 Al; sample pressed at 18 000 psi from powders less than 6 microns, heated in vacuum to 1773 K for 1 hr; CuKα radiation used; data obtained from (422) and (511/333); reported error >2%; zero-point correction of 0.004% determined by graphical extrapolation.
2	437	Frantsevich, I. N., Zhurakovskii, E. A. and Lyashchenko, A. B.	1967	X	293, 393		80.2 Ti, 19.8 total carbon, 0.4 free carbon, and 20.1 theoretical content of metalloid; sample prepared from powder of compound by the vacuum sintering of pressed block; metal-powder method used.
3	422	Richardson, J. H.	1965	X	293-2973		99.3 Ti, 0.40 Mg, 0.15 Cl, 0.10 Fe, 0.02 Ni, and 0.0165 H; prepared by vacuum arc casting; slurry made of 0.19 of powdered carbide with 0.5 ml of a binder solution (Duco cement and acetone 1:20 by volume), a uniform layer of slurry applied to the central portion of the major surface on a graphite heating element and the slurry allowed to dry 5 min.; CuKβ radiation and (111) reflections used.
4	69	Finlay, G. R.	1952		293, 1073		Specimen density 4.93 g cm^{-3}.
5	424	Elliott, R. O. and Kempter, C. P.	1958	X	296-1121		98.1 pure, 1.6 free carbon; specimen obtained from D. H. Sebell at Los Alamos Scientific Laboratories; 325 mesh powder sealed in silica capillary; lattice parameter reported at 296 K is 4.3178 Å; 4.3177 Å at 293 K determined by graphical extrapolation.
6	10	Mauer, F. A. and Bolz, L. H.	1955	X	273-1618		98.5 pure, <1.0 Si, <0.1 Al, Cr, Fe, V, Zr, <0.01 any other impurity, commercial powder; expansion measured in helium atmosphere; zero-point correction of -0.012% determined by graphical extrapolation.
7	59	Bobrowsky, A. R.	1949		299, 866		No details given.
8	145	Gangler, J. J.	1950	I	366-865		Specimen hot pressed.
9	12	Graham, S. A.	1950	T	293-1233		Commercial powder ball milled to ~5 μ, hot pressed into bar and ground to 1.3 in. x 0.14 in. sq; expansion measured in argon atmosphere with increasing temperature on run 1; reported error < 5.0%.
10	12	Graham, S. A.	1950	T	1233-293		The above specimen; expansion measured with decreasing temperature, reported error < 5.0%.
11*	12	Graham, S. A.	1950	T	293-1233		The above specimen; expansion measured with increasing temperature on run 2; reported error < 5.0%.
12*	12	Graham, S. A.	1950	T	1233-293		The above specimen; expansion measured with decreasing temperature on run 2; reported error < 5.0%.
13	447	Shevlin, T. S., Newkirk, H. W., Stevens, E. G. and Greenhouse, H. M.	1956	T	319-1366		Powder prepared by usual extrusion technique; stoichiometric analyzing 0.1 free C; -325 mesh; obtained from Norton Co., Worcester, Mass.; globar-heated horizontal tube furnace with apertures through which expansion of specimen can be observed by pair of filar-head microscopes; zero-point correction of 0.003% determined by graphical extrapolation.
14	448	Houska, C. R.	1961	X	293-1973		$TiC_{0.95}$, 79.35 Ti, 19.05 C (0.15 free C), 0.67 N, 0.10 Fe, 0.035 O, 0.021 Al; total analysis 99.23, total impurity 0.98; specimen prepared by pressing powder of less than 6 microns diameter at 18 000 psi, and then heated in vacuum to 1773 K for 1 hr, data obtained from (422 and 511 333).

* Not shown in figure.

SPECIFICATION TABLE 253. THERMAL LINEAR EXPANSION OF TITANIUM CARBIDE TiC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
15	63	Pears, C.D. and Oglesby, S.	1963	L	293-2905		79.8 Ti, 19.2 C, 0.9 N; elements found by semi-quantitative emission spectrography before exposure 0.6 Fe, 0.5 Zr, after exposure 79.2 Ti, 19.0 C, and 0.6 N; initial length 2.420 in.; Carborundum Co.; hot pressed; run no. E1; density in g cm^{-3} at 298 K before exposure 4.73 by ASTM method B311-58, 4.75 by wax-coating specimen, 4.77 by immersion in xylene, after exposure 4.68 by ASTM method, 4.69 by wax-coating specimen, and 4.82 by immersion in xylene; expansion measured in helium atmosphere; reported error 5%.
16	67	Seibel, R.D. and Mason, G.L.	1958	L	293-1755		Trace Nb; grain size < 0.001 in.; specimen obtained from Firth Sterling Inc. in 1957; density 4.7 g cm^{-3}; expansion measured in vacuum of the order 10^{-6} to 10^{-5} mm Hg and at heating rate about 2-3 C per min.; reported error <5%.
17	429	Shaffer, P.T.B. and Mark, S.D.	1963	L	293-2273		Expansion measured in inert atmosphere with pressure of approximately 1 in. water above atmospheric pressure.
18	70	Engberg, C.J. and Zehms, E.H.	1958	T	293-2645	Sample No. DI-2	Specimen hot pressed; density 4.70 g cm^{-3}; expansion measured in argon atmosphere.
19	70	Engberg, C.J. and Zehms, E.H.	1958	T	2645-293	Sample No. DI-2	Expansion measured with decreasing temperature.
20	70	Engberg, C.J. and Zehms, E.H.	1958	T	293-2813	Sample No. DI-2	The above specimen; expansion measured with increasing temperature on second run.
21	70	Engberg, C.J. and Zehms, E.H.	1958	T	293-2673	Sample No. DI-1	Similar to the above specimen; hot pressed; density 4.70 g cm^{-3}; expansion measured in argon atmosphere.
22*	449	Gropyanov, V.M.	1968	X	1741-2324		Expansion measured under 10^{-4} mm Hg vacuum; specimen held at each temperature for 2 hr before measurement; lattice parameter reported at 1741 K is 4.318 kX (4.327 Å); this curve is here reported using the first given temperature (1741 K) as reference temperature at which $\Delta L/L_0 = 0$.
23	450	Newkirk, H.W. and Sisler, H.H.	1958	X	296-1377		80.04 Ti, 19.40 combined C, 0.10 free C; specimen prepared by extruding TiC-DUCO cement paster, obtained from Norton Co., Worcester, Mass.; heated in vacuum 5 x 10^{-5} mm of mercury; lattice parameter reported at 296 K is 4.3250 Å; 4.3249 Å at 293.2 K determined by graphical extrapolation.
24	433	Krikorian, N.H., Wallace, T.C. and Anderson, J.L.	1963	X	83, 299	$TiC_{0.95}$	5.0 deficient of carbon; powder specimen fragments of Linde single crystal; lattice parameter reported at 299 K is 4.3292 Å; 4.3291 Å at 293 K determined by graphical interpolation.
25	658	Ridley, N. and Stuart, H.	1970	X	293-1221		79.7 Ti, 19.3 C (total), 0.95 C (free), 0.60 N, 0.2 Fe, 0.2 O, <0.05 W, <0.03 Cr, <0.01 Ni; powdered specimen placed in 0.5 mm diameter quartz capillary tube ~ 4 cm long.
26*	660	Samsonov, G.V. and Novmenko, V.Ya.	1969	L	298, 1273	$TiC_{0.96}$	80.55 Ti, 19.25 C (total), made by sintering process at 160 kg/cm^2 at 2373-2873 K for 15 min; cut from 8 x 12-15 mm rod into 2.5 x 2.5 x 12-14 mm bar; annealed at 2273-2473 K, 8 hr, at 1.2 x 10^{-4} mm Hg; measurement made in argon atmosphere; reported error 2.0%.
27*	660	Samsonov, G.V. and Novmenko, V.Ya.	1969	L	298, 1273	$TiC_{0.89}$	Similar to the above specimen except 81.48 Ti and 18.45 C (total).

* Not shown in figure.

SPECIFICATION TABLE 253. THERMAL LINEAR EXPANSION OF TITANIUM CARBIDE TiC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
28*	660	Samsonov, G. V. and Novmenko, V. Ya.	1969	L	298, 1273	$TiC_{0.79}$	Similar to the above specimen except 83.34 Ti and 16.42 C (total).
29*	660	Samsonov, G. V. and Novmenko, V. Ya.	1969	L	298, 1273	$TiC_{0.72}$	Similar to the above specimen except 84.74 Ti and 15.21 C (total).
30*	660	Samsonov, G. V. and Novmenko, V. Ya.	1969	L	298, 1273	$TiC_{0.62}$	Similar to the above specimen except 86.40 Ti and 13.42 C (total).
31*	599	Samsonov, G. V., Grebenkina, V. G., and Klimenko, V. S.	1971	L	293, 2273		Reported error 1.5%.

* Not shown in figure.

DATA TABLE 253. THERMAL LINEAR EXPANSION OF TITANIUM CARBIDE TiC

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.004
1027	0.551
1289	0.789
1539	1.024
1789	1.264
2040	1.494
2353	1.804
CURVE 2	
293	0.000
393	0.086
CURVE 3	
293	0.00*
1273	0.74
1473	0.88
1673	1.15
1873	1.32
2073	1.47
2273	1.71
2373	1.85
2473	1.96
2573	2.08
2673	2.32
2773	2.36
2873	2.43
2973	2.56
CURVE 4	
293	0.000*
1073	0.577
CURVE 5	
296	0.0023*
773	0.3358
975	0.5048
1121	0.6299
CURVE 6	
273	-0.012
299	0.004*
CURVE 6 (cont.)	
477	0.110
681	0.261
885	0.415
1089	0.589
1293	0.769
1495	0.979
1618	1.095
CURVE 7	
299	0.005
866	0.471
CURVE 8	
366	0.047
478	0.119*
589	0.201
700	0.289
811	0.380
865	0.426
CURVE 9	
293	0.000*
773	0.350
973	0.517
1073	0.608
1233	0.752
CURVE 10	
1233	0.733
1073	0.601*
973	0.510*
773	0.350*
293	0.000*
CURVE 11*	
293	0.000
773	0.341
973	0.503
1073	0.585
1233	0.733
CURVE 12*	
1233	0.733
1073	0.601
973	0.510
773	0.350
293	0.000
CURVE 13	
319	0.003
366	0.024
476	0.082
588	0.158
700	0.251
807	0.348
922	0.450
1030	0.556*
1144	0.651
1255	0.757
1366	0.880
CURVE 14	
293	0.00*
773	0.31
1023	0.54
1273	0.86
1523	1.14
1773	1.39
1973	1.65
CURVE 15	
293	0.00*
1060	0.55
1394	0.84
1641	1.05
1908	1.29
1922	1.37
2185	1.60
2460	1.87
2733	2.26
2905	3.91*
CURVE 16	
293	0.000*
CURVE 16 (cont.)	
699	0.275
755	0.326
810	0.372
866	0.418*
922	0.465
977	0.514*
1033	0.560*
1088	0.612
1144	0.671
1199	0.714
1255	0.770*
1310	0.837
1366	0.889*
1422	0.950
1477	1.008
1533	1.057
1588	1.132
1644	1.203
1699	1.277
1755	1.383
CURVE 17	
293	0.000*
1273	0.774
1773	1.323
2273	2.020
CURVE 18	
293	0.00*
1225	0.69
1281	0.72
1381	0.81
1413	0.89
1477	0.89*
1541	0.95
1633	1.01*
1665	1.05
1713	1.10
1773	1.15
1825	1.19
1881	1.24
2057	1.42
2113	1.48
2181	1.56
CURVE 18 (cont.)	
2257	1.63
2341	1.69
2409	1.76
2489	1.85
2617	2.05
2645	2.12
CURVE 19	
2645	2.12*
2573	2.03
2465	1.82*
2369	1.72
2293	1.63
2033	1.40
1949	1.28
1869	1.17
1769	1.08
1673	0.97
1573	0.89
1433	0.82
1337	0.75
1241	0.64
293	0.00*
CURVE 20	
293	0.00*
1221	0.71
1289	0.75
1353	0.81
1397	0.87
1457	0.91
1489	0.93
1549	0.99
1597	1.05
1657	1.11
1829	1.25
1901	1.33
1929	1.33
1993	1.40
2021	1.45
2085	1.52
2137	1.60
2209	1.69
2313	1.80
CURVE 20 (cont.)	
2389	1.88
2429	1.93
2489	2.04
2533	2.10
2593	2.21
2649	2.24
2709	2.33
2765	2.47
2793	2.45
2813	2.53
CURVE 21	
293	0.00*
1273	0.70
1473	0.85
1673	1.02
1873	1.19
2073	1.39
2273	1.60
2473	1.81
2673	2.33
CURVE 22*, †	
1741	0.000
1946	0.000
2044	0.000
2217	-0.005
2324	-0.005
CURVE 23	
296	0.0023*
558	0.1988
833	0.4300
1133	0.6844
1377	0.8971
CURVE 24	
83	-0.0716
299	0.0023*

* Not shown in figure.

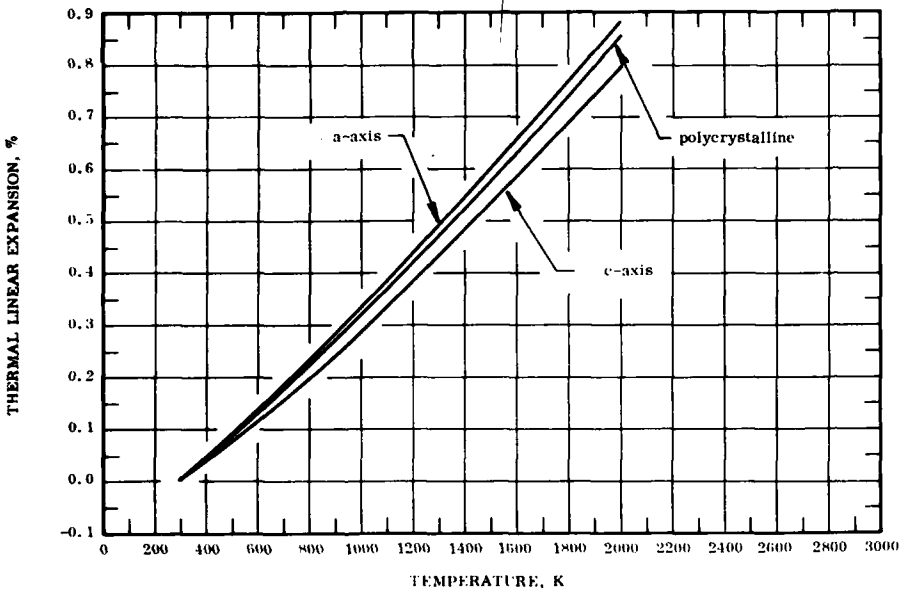
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 253. THERMAL LINEAR EXPANSION OF TITANIUM CARBIDE TiC (continued)

T	$\Delta L/L_0$
CURVE 25	
293	0.000*
331	0.021*
451	0.093
558	0.178
639	0.236
732	0.301
906	0.437
960	0.483
993	0.506
1107	0.604
1221	0.715*
CURVE 26*	
298	0.000
1273	0.648
CURVE 27*	
298	0.000
1273	0.652
CURVE 28*	
298	0.000
1273	0.661
CURVE 29*	
298	0.000
1273	0.665
CURVE 30*	
298	0.000
1273	0.672
CURVE 31*	
293	0.000
2273	1.700

* Not shown in figure.

FIGURE AND TABLE NO. 254R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF TUNGSTEN CARBIDE WC



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	3.7
300	0.003	0.002	0.003	3.7
400	0.045	0.037	0.042	4.0
500	0.089	0.075	0.084	4.3
600	0.135	0.114	0.128	4.5
700	0.183	0.156	0.174	4.6
800	0.232	0.199	0.221	4.8
900	0.282	0.244	0.269	4.9
1000	0.334	0.290	0.319	5.1
1200	0.440	0.387	0.422	5.3
1400	0.550	0.487	0.529	5.4
1600	0.661	0.589	0.637	5.5
1800	0.774	0.693	0.747	5.6
2000	0.886	0.796	0.856	5.7

REMARKS

The recommended values for the axial thermal expansion are based on the data for pure sample and are based on the most recent measurements. The recommended values for the polycrystalline sample are calculated directly from the axial values. This result is recommended in preference to the reported experimental data for polycrystalline samples on the suspicion that those samples exhibit preferential orientation and are not randomly oriented. The recommended values are considered accurate to ± 5% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.110 + 3.409 \times 10^{-4} T + 1.276 \times 10^{-7} T^2 - 2.453 \times 10^{-11} T^3$

// c-axis: $\Delta L/L_0 = -0.0873 + 2.564 \times 10^{-4} T + 1.498 \times 10^{-7} T^2 - 2.859 \times 10^{-11} T^3$

polycrystalline: $\Delta L/L_0 = -0.103 + 3.133 \times 10^{-4} T + 1.345 \times 10^{-7} T^2 - 2.571 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are calculated primarily by differentiating the above equation for polycrystalline sample and are considered accurate to about ± 7%.

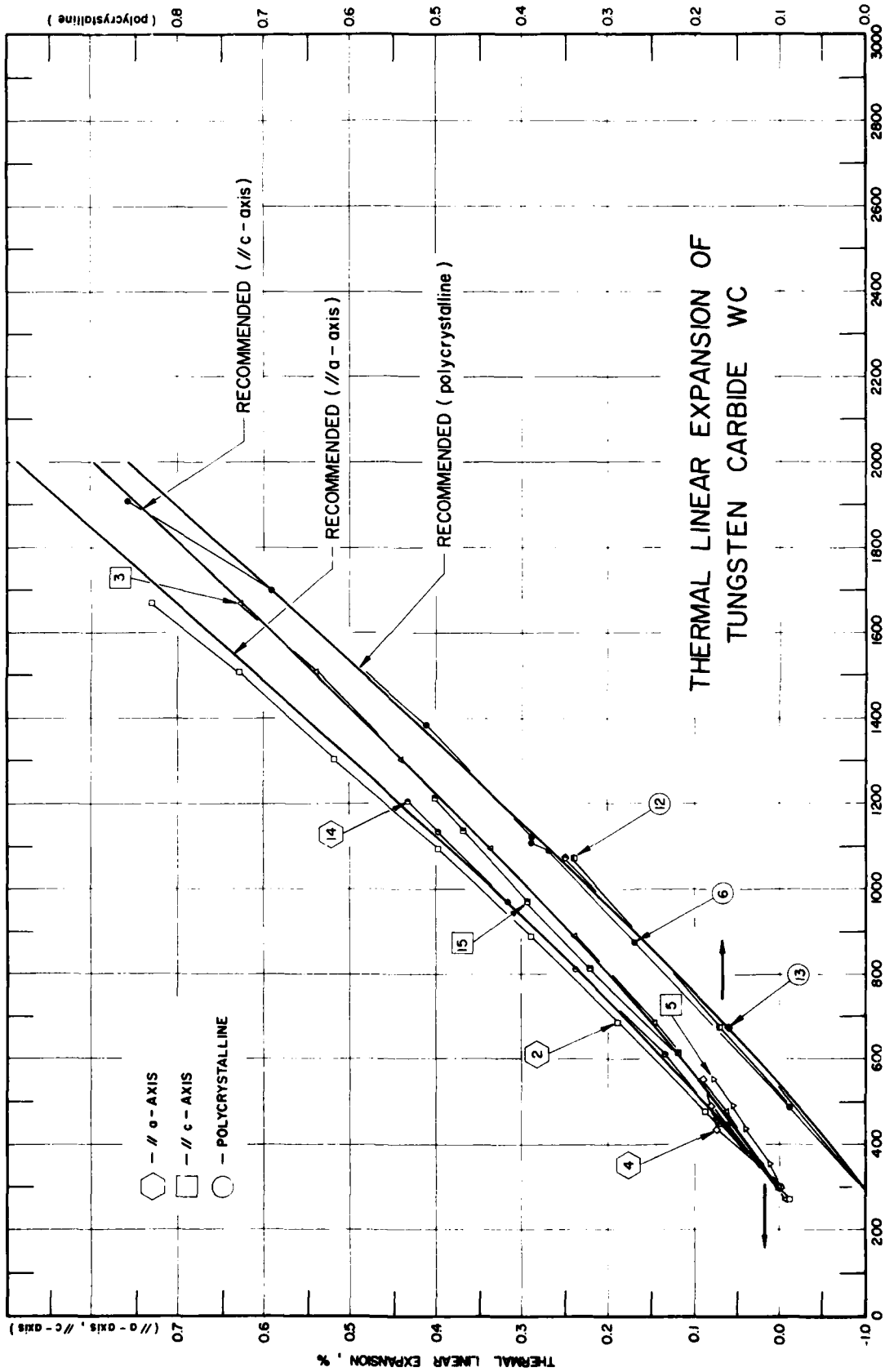

THERMAL LINEAR EXPANSION OF
TUNGSTEN CARBIDE WC
RECOMMENDED (// c - axis)
RECOMMENDED (// a - axis)
RECOMMENDED (polycrystalline)
— // a - AXIS
— // c - AXIS
— POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
(// a - axis , // c - axis)
(polycrystalline)
TEMPERATURE , K

FIGURE 254

SPECIFICATION TABLE 254. THERMAL LINEAR EXPANSION OF TUNGSTEN CARBIDE WC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	437	Frantsevich, I.N., Zhurakovskii, E.A., and Lyashchenko, A.B.	1967	X	293, 1473		93.4 W, 6.1 total carbon, 0.1 free carbon; 6.12 theoretical content of metalloid; sample prepared by the vacuum sintering of pressed block.
2	10	Mauer, F.A. and Bolz, L.H.	1955	X	273-1669		99.5+ pure, 6.07 C (6.13 C theoretical) < 0.1 Si, < 0.01 any other impurity; commercial powder mixed with excess carbon, sintered; expansion measured in helium atmosphere along a-axis.
3	10	Mauer, F.A. and Bolz, L.H.	1955	X	273-1669		The above specimen; expansion measured along c-axis.
4	661	Desphande, V.T., Pawar, R.R., and Surjanarayana, S.V.	1968	X	298-553		Lattice parameter expansion measured along a-axis; 2.9064 Å reported at 298 K.
5	661	Desphande, V.T., et al.	1968	X	298-553		Lattice parameter expansion measured along c-axis; 2.8374 Å reported at 298 K.
6	63	Pears, C.D.	1963	I	294-2427		93.9 W, 6.15 C, <0.1 N, element found by semi-quantitative emission spectrography before exposure 0.3 Si, 0.4 Fe, after exposure 94.1 W, 5.95 C, and < 0.1 N; initial length 2.232 in., final length 2.365 in.; Carborundum Co.; hot pressed; Run No. E4; incipient melting evident on post inspection; density in g cm^{-3} at 298 K before exposure 15.0 by ASTM method, B311-58, 15.1 by wax-coating specimen and by immersion in xylene after exposure 13.1 by ASTM method, 13.2 by wax-coating specimen, and 14.7 by immersion in xylene; expansion measured in helium atmosphere.
7*	446	Panov, V.S. and Meerson, G.A.	1968	L	291, 693		Hot pressed specimen, 16 mm diameter x 5 to 10 mm high, annealed 48 hr at 1723 K.
8*	446	Panov, V.S. and Meerson, G.A.	1968	L	291, 693		Similar to the above specimen.
9	446	Panov, V.S. and Meerson, G.A.	1968	L	291, 693		1.0 TaC; carbides mixed 8 hr in ball mill, calcined 2 hr at 2473 K to 2573 K in hydrogen atmosphere, milled 96 hr in alcohol; specimen 16 mm diameter x 5 to 10 mm high prepared by hot pressing at 2473 K to 2573 K under 250 kg cm^{-2} pressure; homogenized 7.5 hr at 2273 K and annealed 48 hr at 1723 K; x-ray analysis showed grains of TaC.
10*	446	Panov, V.S. and Meerson, G.A.	1968	L	291, 693		0.54 NbC; similar to the above specimen.
11*	446	Panov, V.S. and Meerson, G.A.	1968	L	291, 693		1.08 NbC; similar to the above specimen except solid solution verified by x-ray analysis.
12	662	Tumanov, V.I., Funke, V.F., Baskin, M.L., and Novikova, T.A.	1964	L	293-1073		WC particle size 2.7 μ.
13*	662	Tumanov, V.I., et al.	1964		293-1073		99.0 WC, 1.0 Co; mean particle size of WC 2.7 μ.
14	658	Ridley, N. and Stuart, H.	1970	X	293-1207		93.6 W, 6.16 C (total), 0.08 C (free), 0.05 O, < 0.02 Mo, 0.01 N, < 0.01 each As, Cr, Ni, P, S; powdered specimen placed in 0.5 mm diameter quartz capillary tube ~4 cm long; expansion measured along a-axis.
15	658	Ridley, N. and Stuart, H.	1970	X	293-1213		Similar to the above specimen; expansion measured along c-axis.

* Not shown in figure.

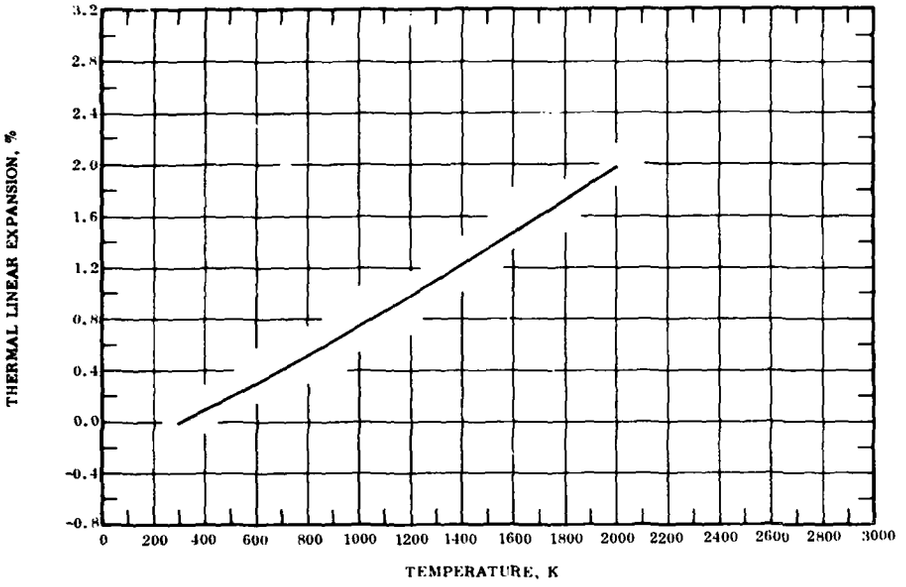
DATA TABLE 254. THERMAL LINEAR EXPANSION OF TUNGSTEN CARBIDE WC

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
1473	0.767
CURVE 2	
273	-0.011
299	0.003
479	0.089
685	0.189
891	0.292
1097	0.399
1303	0.519
1509	0.629
1669	0.732
CURVE 3	
273	-0.008*
299	0.003*
479	0.063
685	0.147
891	0.239
1097	0.337
1303	0.443
1509	0.542
1669	0.627
CURVE 4	
298	0.000*
355	0.024
437	0.076
491	0.083*
553	0.093
CURVE 5	
298	0.000*
355	0.011
437	0.039
491	0.056
553	0.078
CURVE 6	
294	0.00*
487	0.09
876	0.27
1092	0.37
1110	0.39
1124	0.39*
1383	0.51
1699	0.69
1908	0.86
2205	1.07
2427	1.39
2427	1.77
2427	2.00
CURVE 7*	
291	-0.001
693	0.156
CURVE 8*	
291	-0.001
493	0.152
CURVE 9	
291	-0.001*
693	0.168
CURVE 10*	
291	-0.001
693	0.164
CURVE 11*	
291	-0.001
693	0.168
CURVE 12	
293	0.00*
673	0.17
1073	0.34
CURVE 13*	
293	0.00
673	0.16
1073	0.35
CURVE 14	
293	0.000*
448	0.072
610	0.134
813	0.237
969	0.317
1136	0.399
1207	0.434
CURVE 15	
293	0.000*
447	0.063*
613	0.130*
814	0.222
972	0.296
1140	0.370
1213	0.402

* Not shown in figure.

FIGURE AND TABLE NO. 255R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF URANIUM MONOCARBIDE UC



RECOMMENDED VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

T	$\Delta L/L_0$	α
293	0.000	9.8
300	0.008	9.8
400	0.108	10.1
500	0.207	10.3
600	0.311	10.6
700	0.421	10.8
800	0.533	11.0
900	0.642	11.3
1000	0.756	11.4
1200	0.988	11.8
1400	1.227	12.1
1600	1.471	12.3
1800	1.719	12.5
2000	1.970	12.6

REMARKS

The recommended values are based on the data for sintered samples (curves 38-40, and 44) and hot-pressed (curves 45 and 50) and are considered accurate to about ± 5%. The data reported for arc-cast samples (curves 2-11) are up to 20% higher than the recommended values. The recommended values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.272 + 8.877 \times 10^{-4}\, T + 1.634 \times 10^{-7}\, T^2 - 2.336 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are calculated primarily by differentiating the above equation and are considered accurate to about ± 7%.

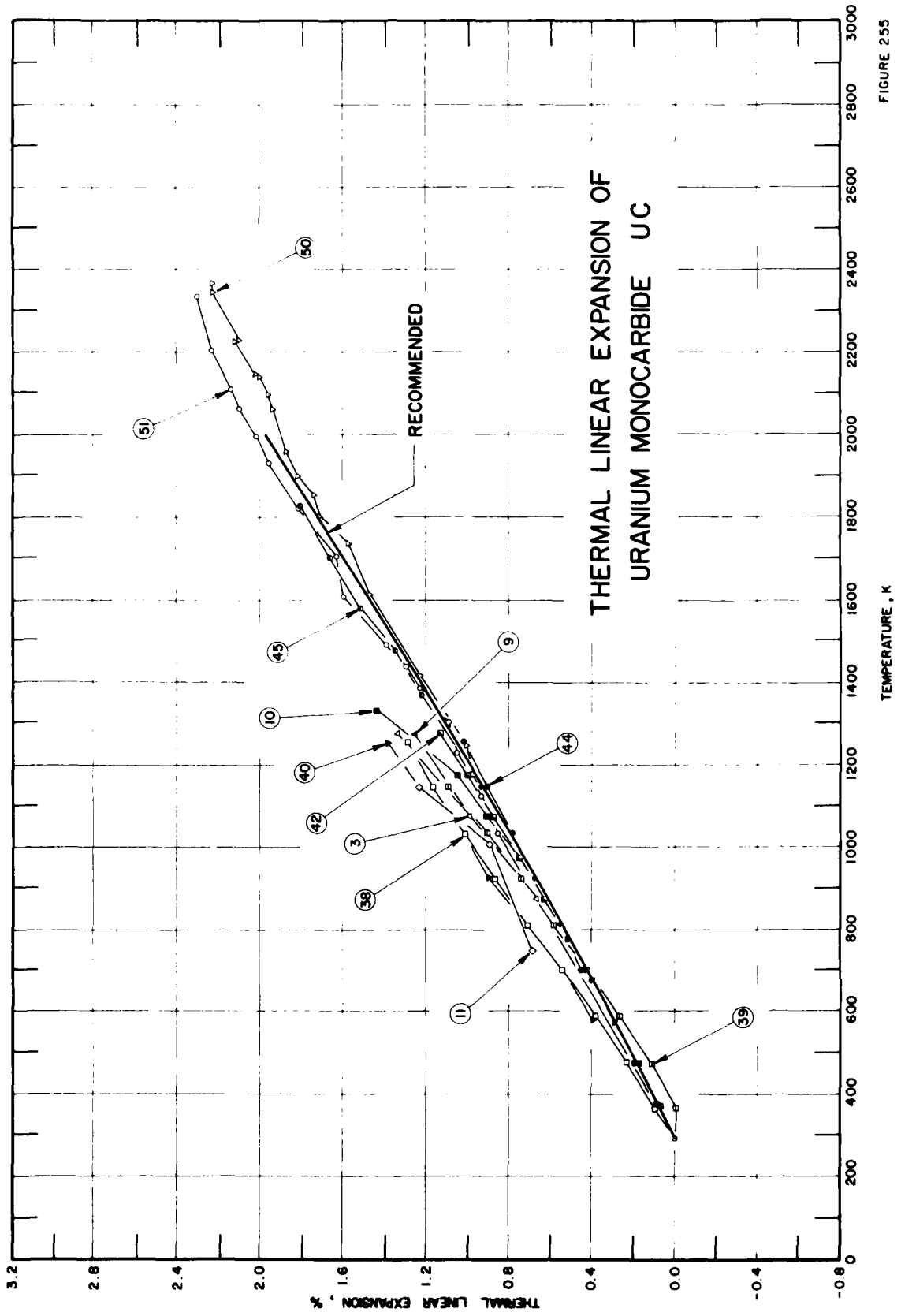

THERMAL LINEAR EXPANSION OF
URANIUM MONOCARBIDE UC
RECOMMENDED
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
-0.4
-0.8
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
50
51
45
9
10
40
44
42
3
38
11
39

FIGURE 255

SPECIFICATION TABLE 255. THERMAL LINEAR EXPANSION OF URANIUM MONOCARBIDE UC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	731	Secrest, A.C.	1959	L	293-1223		95.8 U, 4.8 C; specimen tested as-cast; expansion measured with increasing temperature; specimen made by arc melting freshly pickled center cut uranium; dimensions; cylinderical 3.75 in. x 1.75 in. long; 0.500 in. x 0.050-0.090 in. thick with crush spectrographic carbon (0.25 in. x 0.625 in. pieces) in He atmosphere of 10 to 20 in. Hg; density was 13.49 cm^{-3}; 98% of theoretical; no porosity reported.
2*	731	Secrest, A.C.	1959	L	1223-293		The above specimen; expansion with decreasing temperature.
3	698	Strasser, A., Stahl, D., Taylor, K., and Anderson, T.	1963	L	303-1273	Arc-cast UC	Arc-cast uranium carbide, differential dilatometer used for measurement; difference in expansion with increasing temperature sensed by a dial gauge; first run; reported error 5%.
4*	698	Strasser, A., et al.	1963	L	1633-303	Arc-cast UC	The above specimen; expansion with decreasing temperature; first run.
5*	698	Strasser, A., et al.	1963	L	303-1633	Arc-cast UC	The above specimen; expansion with increasing temperature; sensed by a dial gauge; second run.
6*	698	Strasser, A., et al.	1963	L	293-1273	Arc-cast UC	Similar to the above specimen; expansion measured with increasing temperature first heating using a linear variable differential transformer to sense difference in expansion.
7*	698	Strasser, A., et al.	1963	L	1633-293	Arc-cast UC	The above specimen; expansion measured with decreasing temperature (first cooling).
8*	698	Strasser, A., et al.	1963	L	293-1633	Arc-cast UC	The above specimen; expansion measured with increasing temperature (second heating).
9	698	Strasser, A., et al.	1963	L	293-1633	Arc-cast UC	Data reported is overall value (mean) of expansion using both dial gauge and linear variable differential transformer.
10	732	Mẽndes-Peñaloso, R. and Taylor, R.E.	1964	T	293-1328	DH-303	4.35 C; specimen dimensions 0.5 in. diameter by 6 in. long; arc-cast; measured in helium atmosphere; data obtained by personal communication from authors subsequent to publication of article; reported error 1-1.5%.
11	732	Mẽndes-Peñaloso, R. and Taylor, R.E.	1964	T	1328-743		Expansion given in decreasing temperatures; reported error 1-1.5%.
12*	732	Mẽndes-Peñaloso, R. and Taylor, R.E.	1964	T	743-1923		Expansion given in increasing temperatures on second thermal cycle.
13*	732	Mẽndes-Peñaloso, R. and Taylor, R.E.	1964	T	293-1173	DH-304	4.43 C; specimen dimensions 0.5 in. diameter by 6 in. long; arc-cast measured in helium atmosphere.
14*	732	Mẽndes-Peñaloso, R. and Taylor, R.E.	1964	T	1173-285		Expansion given in decreasing temperatures.
15*	732	Mẽndes-Peñaloso, R. and Taylor, R.E.	1964	T	293-1173	DH-305	4.59 C; specimen dimensions 0.5 in. diameter by 6 in. long; arc-cast; measured in helium atmosphere.
16*	732	Mẽndes-Peñaloso, R. and Taylor, R.E.	1964	T	1173-285		Expansion given in decreasing temperatures.
17*	732	Mẽndes-Peñaloso, R. and Taylor, R.E.	1964	T	293-1173	DH-318	4.71 C; specimen dimensions 0.5 in. diameter by 6 in. long; arc-cast; measured in helium atmosphere.
18*	732	Mẽndes-Peñaloso, R. and Taylor, R.E.	1964	T	1173, 287		Expansion measured in decreasing temperature.

* Not shown in figure.

SPECIFICATION TABLE 255. THERMAL LINEAR EXPANSION OF URANIUM MONOCARBIDE UC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
19*	732	Mendes-Peñaloso, R. and Taylor, R.E.	1964	T	293-2273	HF-44	4.9 C; specimen dimensions 0.5 in. diameter by 6 in. long; arc-cast; measured in helium atmosphere; reported error 1-1.5%.
20*	732	Mendes-Peñaloso, R. and Taylor, R.E.	1964	T	2273,285		Expansion given in decreasing temperature; reported error 1-1.5%.
21*	732	Mendes-Peñaloso, R. and Taylor, R.E.	1964	T	293-2273	DH-308	5.04 C; specimen dimensions 0.5 in. diameter by 6 in. long; arc-cast; measured in helium atmosphere; reported error 1-1.5%.
22*	732	Mendes-Peñaloso, R. and Taylor, R.E.	1964	T	2273-285		Expansion measured in decreasing temperatures.
23*	732	Mendes-Peñaloso, R. and Taylor, R.E.	1964	T	293-2273	DH-301	5.05 C; specimen dimensions 0.5 in. diameter by 6 in. long; arc-cast; measured in helium atmosphere; reported error 1-1.5%.
24*	732	Mendes-Peñaloso, R. and Taylor, R.E.	1964	T	2273-285		Expansion given in decreasing temperatures.
25*	732	Mendes-Peñaloso, R. and Taylor, R.E.	1964	T	293-2273	DH-302	5.08 C; specimen dimensions 0.5 in. diameter by 6 in. long; arc-cast; measured in helium atmosphere; (data received as a personal communication from authors and completed subsequent to publication of article).
26*	732	Mendes-Peñaloso, R. and Taylor, R.E.	1964	T	2273-285		Expansion given in decreasing temperatures.
27*	732	Mendes-Peñaloso, R. and Taylor, R.E.	1964	T	293-2073	DH-339	5.24 C; specimen dimensions 0.5 in. diameter by 6 in. long; arc-cast; measured in helium atmosphere; reported error 1-1.5%.
28*	732	Mendes-Peñaloso, R. and Taylor, R.E.	1964	T	2073-285		Expansion given in decreasing temperatures.
29*	733	Meerson, G.A., Kotelnikov, R.B., and Bosklikov, S.N.	1960	L	293-873		~95 U, ~5 C; grain size 10-20 μ single phase; specimen pressed from UC powder and sintered in a vacuum ~10 mm Hg furnace; reported lattice parameter 4.9512 Å specific gravity in kerosene, 12.979-cm^{-3}, X-ray density 13.63 g cm^3.
30*	734	Taylor, K.M. and McMurtry, C.H.	1961	L	298-1523		94.5-95.4 U, 4.65-4.90 C, 0.65-0.35 O, trace -0.1 each N and F; dimensions 6.4 x 12.7 x 76.2 mm; specimen made by ball milling and pelletizing, then heated to 2023 K for 8 hr, density 12.68 g cm^{-3}; particle size ~2 μ.
31*	439	Nowotny, H.	1961	X	293-1773		A small amount of UC_2 present; almost stoichiometric composition; lattice parameter reported at 293 K as 4.952 Å.
32*	715	Ferguson, I.F., Street, R.S., and Waters, T.N.	1961	X	293-973		Specimen prepared by heating UO_2 and graphite in vacuum; analysed as $UO_{0.83}$; ground under argon and placed in silica capillary and evacuated; lattice parameter reported at 293 K as 4.9601 Å; expansion measured along cubic cell edge.
33*	735	Kalish, H.S. and Crane, J.	1962	L	298-1273	1H-296919	Containing 4.37 C; dimensions 8 mm diameter x 25.4 mm long; sintered rod; density 13.83 g cm^3 (99% theoretical) specimen formed by grinding.
34*	735	Kalish, H.S. and Crane, J.	1962	L	299-1273	1H-296927	Similar to the above except containing 4.30 C; sintered rod; density 13.61 g cm^3 (97% theoretical).
35*	735	Kalish, H.S. and Crane, J.	1962	L	298-1273	1H-296922	Similar to the above except containing 4.73 C; cast rod; density 13.42 g cm^3 (98% theoretical).
36*	735	Kalish, H.S. and Crane, J.	1962	L	306-1273	1H-296934	Containing 4.73 C; cast bar; density 13.53 g cm^3 (99% theoretical).
37*	735	Kalish, H.S. and Crane, J.	1962	L	305-1273	1H-296938	Containing 4.74 C; cast bar; density 13.66 g cm^3 (100% theoretical).

* Not shown in figure.

SPECIFICATION TABLE 255. THERMAL LINEAR EXPANSION OF URANIUM MONOCARBIDE UC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
38	736	Tripler, A. B., Snyder, M.J., and Duckworth, W.H.	1959	L	366-1255		Sintered specimen; expansion measured in 5 x 10^{-5} mm Hg vacuum with temperature increasing at 2.8 K per minute.
39	736	Tripler, A. B., et al.	1959	L	1255-366		The above specimen; expansion with decreasing temperature.
40	736	Tripler, A. B., et al.	1959	L	366-1255		The above specimen; expansion with increasing temperature on second test.
41*	736	Tripler, A. B., et al.	1959	L	1255-366		The above specimen; expansion with decreasing temperature.
42	737	Smith, C.A. and Rough, F.	1959	C	293-1273		95 U, 5 C; excess carbon; 0.75 in. diameter x 6 in. long; expansion measured with increasing temperature; density 13.36 g cm^{-3}; 98% of theoretical density.
43*	737	Smith, C.A. and Rough, F.	1959	C	1273-293		The above specimen; expansion with decreasing temperature.
44	738	DeCrescente, M.A. and Miller, A.D.	1963	L	700-1255		Vacuum sintered specimen, 0.96 cm long x 0.62 cm diameter; 93% of theoretical density; expansion measured in vacuum with temperature increasing at 2.8 C/minute.
45	738	DeCrescente, M.A. and Miller, A.D.	1963	L	700-1811		95.11 U, 4.89 C; hot pressed specimen: 4.96 cm long x 0.62 cm diameter; specimen 86% theoretical density; expansion measured in argon atmosphere with temperature increasing at 3.9 C/minute.
46*	738	DeCrescente, M.A. and Miller, A.D.	1963	L	700-1255		4.8 C; dimensions: 62 cm diameter x 0.96 cm; made by vacuum sintering; 93% of theoretical density.
47*	738	DeCrescente, M.A. and Miller, A.D.	1963	L	700-1265		4.89 C; similar to the above except hot-pressed.
48*	702	Bocker, S. and Boucher, R.	1969	L	293-1273	Composition No. 1	95.2 U, 4.79 C (50 at.% U, 50 at.% C); rough-cast 1900 C - 110 hr; crystalline parameter 4.9610 ± 0.0005 (Å); phase UC + UC_2 observed.
49*	702	Bocker, S. and Boucher, R.	1969	L	293-1273	Composition No. 2	94.81 U, 5.183 C (52 at.% U, 48 at.% C); rough-cast 4900 C - 110 hr; phase UC + UC_2 observed.
50	714	Benz, R. and Farr, J.D.	1971	X	293-2367	$UC_{1.00}$	10 mm diameter cylinder; alloy of Uranium and carbon were melted and crushed to powders, mixture was cold pressed into a cylinder annealed for 2 min at 2373 K; reground into a powder with pestle; process was reported three times, then the specimen finally weighed 1.3 g up to 1873 K; specimen was heated in a high vacuum; at higher temperatures, it was heated in a 5 Torr argon atmosphere, reference lattice parameter is 4.962 Å at 293 K.
51	714	Benz, R. and Farr, J.D.	1971	X	293-2337	$UC_{1.02}$	Similar to the above except slightly different composition; reference lattice parameter is 4.962 Å at 293 K.
52*	714	Benz, R. and Farr, J.D.	1971	X	2062-2508	$UC_{1.08}$	Similar to the above except slightly different composition; reference lattice parameter is 5.097 Å at 2062 K; curve is here reported using 2062 K as reference temperature at which $\Delta L/L_0 = 0$.
53*	714	Benz, R. and Farr, J.D.	1971	X	2210-2474	$UC_{1.13}$	Similar to the above except slightly different composition; reference lattice parameter is 5.134 Å at 2210 K; curve is here reported using 2210 K as reference temperature at which $\Delta L/L_0 = 0$.
54*	714	Benz, R. and Farr, J.D.	1971	X	2356-2448	$UC_{1.41}$	Similar to the above except slightly different composition; reference lattice parameter is 5.249 Å at 2356 K; curve is here reported using 2356 K as reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

DATA TABLE 255. THERMAL LINEAR EXPANSION OF URANIUM MONOCARBIDE UC

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
373	0.076
473	0.177
573	0.284
673	0.395
773	0.509
873	0.625
973	0.746
1073	0.868
1173	0.994
1223	1.059
CURVE 2*	
1223	1.059
1173	0.991
1073	0.857
973	0.726
873	0.602
773	0.480
673	0.363
573	0.252
473	0.146
373	0.040
293	-0.042
CURVE 3	
303	0.0093*
473	0.1674*
673	0.3867
873	0.6705
1073	0.9872
1273	1.3328
CURVE 4*	
1633	1.8221
1473	1.5795
1273	1.2901
1073	1.0010
873	0.7239
673	0.4668
473	0.2106
303	0.0117

T	$\Delta L/L_0$
CURVE 5*	
303	0.0100
473	0.1800
673	0.4318
873	0.6940
1073	0.9571
1273	1.2322
1473	1.4968
1633	1.6991
CURVE 6*	
293	0.000
473	0.149
673	0.368
873	0.620
1073	0.963
1273	1.264
CURVE 7*	
1633	1.688
1473	1.463
1273	1.195
1073	0.920
873	0.638
673	0.380
473	0.163
293	0.000
CURVE 8*	
293	0.000
473	0.192
673	0.429
873	0.713
1073	1.014
1273	1.313
1473	1.616
1633	1.849
CURVE 9	
293	0.000*
473	0.174
673	0.406
873	0.678
1073	0.967

T	$\Delta L/L_0$
CURVE 9 (cont.)	
1273	1.254
1473	1.534
1633	1.768
CURVE 10	
293	0.00*
373	0.09
473	0.19
573	0.29*
673	0.40*
773	0.52*
873	0.64*
973	0.76*
1073	0.90
1173	1.05
1328	1.44
CURVE 11	
1328	1.44
1144	1.23
1004	0.89
743	0.68
CURVE 12*	
743	0.68
1083	1.14
1328	1.51
1603	1.96
1923	2.64
CURVE 13*	
293	0.00
373	0.09
473	0.19
573	0.29
673	0.40
773	0.51
873	0.63
973	0.76
1073	0.90
1173	1.10

T	$\Delta L/L_0$
CURVE 14*	
1173	1.10
1066	1.29
671	0.79
285	0.43
CURVE 15*	
293	0.00
373	0.09
473	0.19
573	0.29
673	0.40
773	0.51
873	0.62
973	0.75
1073	0.87
1173	1.01
CURVE 16*	
1173	1.01
1002	0.89
858	0.73
285	0.18
CURVE 17*	
293	0.00
373	0.08
473	0.19
573	0.29
673	0.40
773	0.51
873	0.62
973	0.74
1073	0.85
1173	0.97
CURVE 18*	
1173	0.97
287	0.06
CURVE 19*	
293	0.00
373	0.08

T	$\Delta L/L_0$
CURVE 19 (cont.)	
473	0.19
573	0.29
673	0.40
773	0.51
873	0.62
973	0.74
1073	0.85
1173	0.97
1273	1.10
1473	1.35
1673	1.61
1873	1.89
2073	2.17
2273	2.46
CURVE 20*	
2273	2.46
285	0.06
CURVE 21*	
293	0.00
373	0.08
473	0.19
573	0.29
673	0.40
773	0.51
873	0.62
973	0.74
1073	0.85
1173	0.98
1273	1.10
1473	1.35
1673	1.61
1873	1.89
2073	2.17
2273	2.46
CURVE 22*	
2273	2.46
1919	2.05
1555	1.53
1311	1.25
1129	1.02
285	0.66

T	$\Delta L/L_0$
CURVE 23*	
293	0.00
373	0.08
473	0.19
573	0.29
673	0.40
773	0.51
873	0.62
973	0.74
1073	0.85
1173	0.97
1273	1.10
1473	1.35
1673	1.62
1873	1.89
2073	2.18
2273	2.46
CURVE 24*	
2273	2.460
285	0.055
CURVE 25*	
293	0.00
373	0.09
473	0.18
573	0.29
673	0.39
773	0.50
873	0.60
973	0.70
1073	0.83
1173	0.95
1273	1.08
1473	1.30
1673	1.55
1873	1.80
2073	2.07
2273	2.34
CURVE 26*	
2273	2.33
1886	1.84
1787	1.67
285	0.04

* Not shown in figure.

DATA TABLE 255. THERMAL LINEAR EXPANSION OF URANIUM MONOCARBIDE UC (continued)

T	$\Delta L/L_0$
CURVE 27*	
293	0.00
373	0.08
473	0.19
573	0.29
673	0.40
773	0.52
873	0.64
973	0.76
1073	0.89
1173	1.02
1273	1.15
1473	1.42
1673	1.70
1873	1.99
2073	2.27
CURVE 28*	
2073	2.28
285	0.04
CURVE 29*	
293	0.000
873	0.516
1273	0.980
1773	1.716
CURVE 30*	
298	0.004
478	0.179
489	0.183
498	0.187
696	0.410
702	0.420
708	0.419
898	0.643
911	0.663
924	0.667
1109	0.897
1117	0.915
1128	0.913
1303	1.136
1313	1.148
1328	1.154
1504	1.402
1510	1.382
1523	1.389

T	$\Delta L/L_0$
CURVE 31*	
293	0.000
843	0.404
1023	0.646
1123	0.929
1273	0.889
1373	1.070
1773	1.676
CURVE 32*	
293	0.000
373	0.084
473	0.207
573	0.310
673	0.441
773	0.510
873	0.651
973	0.733
CURVE 33*	
298	0.002
373	0.045
473	0.129
573	0.271
673	0.401
773	0.519
873	0.645
973	0.771
1073	0.897
1173	1.007
1273	1.133
CURVE 34*	
299	0.005
373	0.075
473	0.169
573	0.295
673	0.421
773	0.551
873	0.673
973	0.811
1073	0.941
1173	1.051
1273	1.177

T	$\Delta L/L_0$
CURVE 35*	
298	0.002
373	0.034
473	0.101
573	0.207
673	0.341
773	0.475
873	0.585
973	0.695
1073	0.805
1173	0.907
1273	1.009
CURVE 36*	
306	0.011
373	0.069
473	0.149
573	0.279
673	0.406
773	0.544
873	0.663
973	0.782
1073	0.901
1173	1.012
1273	1.119
CURVE 37*	
305	0.007
373	0.046
473	0.125
573	0.239
673	0.353
773	0.483
873	0.605
973	0.731
1073	0.837
1173	0.943
1273	1.041
CURVE 38	
366	0.091
477	0.232*
589	0.383
700	0.534
811	0.708
922	0.860
1033	1.012

T	$\Delta L/L_0$
CURVE 38 (cont.)	
1144	1.164
1255	1.282
CURVE 39	
1255	1.282*
1144	1.089
1033	0.904
922	0.739
811	0.578
700	0.413
589	0.262
477	0.111*
366	-0.033
CURVE 40	
366	0.094*
477	0.236*
589	0.388*
700	0.556*
811	0.718*
922	0.894
1033	1.052
1144	1.226
1255	1.386
CURVE 41*	
1255	1.386
1144	1.208
1033	1.035
922	0.866
811	0.700
700	0.532
589	0.366
477	0.218
366	0.075
CURVE 42	
293	0.000
373	0.076
473	0.177
573	0.284
673	0.395
773	0.509
873	0.625
973	0.746

T	$\Delta L/L_0$
CURVE 42 (cont.)	
1073	0.868
1173	0.994
1273	1.124
CURVE 43*	
1273	1.191
1173	1.055
1073	0.921
973	0.790
873	0.662
773	0.538
673	0.416
573	0.299
473	0.188
373	0.082
293	0.000
CURVE 44	
700	0.443
811	0.552*
922	0.670
1033	0.787
1144	0.903
1255	1.019
CURVE 45	
700	0.407*
811	0.531
922	0.658*
1033	0.790*
1144	0.926
1255	1.066
1366	1.210
1477	1.351*
1589	1.511
1700	1.667
1811	1.828
CURVE 46*	
700	0.433
811	0.552
922	0.670
1033	0.787
1144	0.903
1255	1.019

T	$\Delta L/L_0$
CURVE 47*	
700	0.433
811	0.552
922	0.670
1033	0.781
1144	0.903
1265	1.019
CURVE 48*	
293	0.000
873	0.577
1273	1.062
CURVE 49*	
293	0.000
873	0.586
1273	1.092
CURVE 50	
293	0.000*
1033	0.786
1176	0.967
1243	1.007
1414	1.229
1613	1.471
1737	1.571
1801	1.713
1856	1.733
1899	1.813
1961	1.874
2061	1.934
2094	1.975
2139	1.999
2147	2.015
2222	2.116
2231	2.095
2345	2.227
2367	2.227
CURVE 51	
293	0.000*
1034	0.846
1121	0.927
1224	1.027
1300	1.088
1384	1.229

* Not shown in figure.

DATA TABLE 255. THERMAL LINEAR EXPANSION OF URANIUM MONOCARBIDE UC (continued)

T	$\Delta L/L_0$
CURVE 51 (cont.)	
1438	1.289
1487	1.390
1607	1.592
1703	1.632
1820	1.813
1930	1.954
1993	2.015
2061	2.095
2110	2.136
2206	2.237
2337	2.297
CURVE 52*,†	
2062	0.000
2110	0.000
2235	0.157
2320	0.255
2355	0.353
2393	0.353
2437	0.313
2508	0.353
CURVE 53*,†	
2210	0.000
2260	0.000
2317	0.058
2372	0.097
2378	0.136
2430	0.136
2455	0.272
2474	0.292
CURVE 54*,†	
2356	0.000
2356	0.114
2370	0.076
2403	0.114
2427	0.133
2448	0.019

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

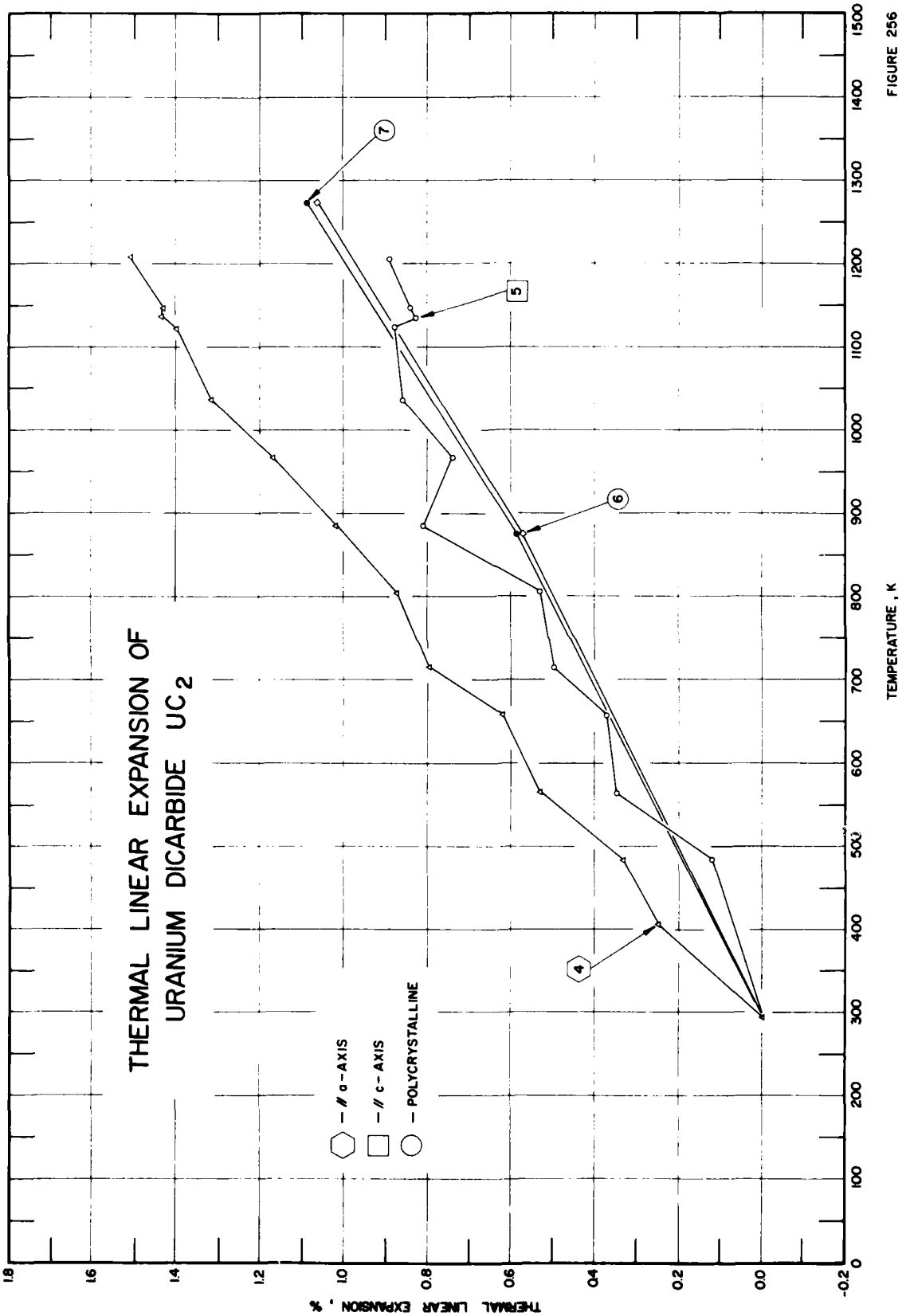

THERMAL LINEAR EXPANSION OF
URANIUM DICARBIDE UC_2
— // a-AXIS
— // c-AXIS
— POLYCRYSTALLINE
4
5
6
7
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 256

SPECIFICATION TABLE 256. THERMAL LINEAR EXPANSION OF URANIUM DICARBIDE UC_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	712	Bowman, A.L., Arnold, G.P., Witteman, W.G., and Wallace, T.C.	1966	X	1340-2051		Tetragonal structure; prepared from high purity uranium and graphite by arc melting and ground to powder; expansion measured along a-axis; lattice parameter reported at 1340 K as 5.065 Å; this curve is here reported using the first given temperature 1340 K as the reference temperature at which $\Delta L/L_0 = 0$.
2*	712	Bowman, A.L., et al.	1966	X	1340-2051		The above specimen; expansion measured along c-axis; lattice parameter reported at 1350 K as 6.055 Å; this curve is here reported using the first given temperature 1350 K as the reference temperature at which $\Delta L/L_0 = 0$.
3*	712	Bowman, A.L., et al.	1966	X	2033-2591		The above specimen; cubic structure; transition occurred at 2033 K; lattice parameter reported at 2033 K as 5.491 Å; this curve is here reported using the first given temperature 2033 K as the reference temperature at which $\Delta L/L_0 = 0$.
4	715	Ferguson, I.F., Street, R.S., and Waters, T.N.	1961	X	293-1208	$UC_{1.82}$	Prepared by argon arc fusion of uranium and graphite; ground and placed in silica capillary and evacuated; expansion reported as the average of several runs along the a-axis; lattice parameter reported at 293 K as 3.5254 Å.
5	715	Ferguson, I.F., et al.	1961	X	293-1208		The above specimen; expansion measured along the c-axis; lattice parameter reported at 293 K as 6.0025 Å.
6*	714	Benz, R. and Farr, J.D.	1971	X	2097-2331	$UC_{1.65}$	Made from 10 mm diameter cylinder alloy of uranium and carbon melted and crushed in a powder; mixture was cold pressed into a cylinder annealed for 2 min. at 2373 K; reground into a powder with prestle; process repeated three times; the specimen weighed 1.3 gm; expansion measured in 5 Torr argon atmosphere; lattice parameter reported at 2097 K as 5.361 Å; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
7*	714	Benz, R. and Farr, J.D.	1971	X	2085-2412	$UC_{1.71}$	Similar to the above except different composition; lattice parameter reported at 2085 K as 5.386 Å; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
8*	714	Benz, R. and Farr, J.D.	1971	X	2048-2376	$UC_{1.80}$	Similar to the above except different composition; lattice parameter reported at 2048 K as 5.426 Å; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
9*	714	Benz, R. and Farr, J.D.	1971	X	2136-2314	$UC_{1.90}$	Similar to the above except different composition; lattice parameter reported at 2136 K as 4.483 Å; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
10*	714	Benz, R. and Farr, J.D.	1971	X	2033-2312	$UC_{2.5}$	Similar to the above except different composition; lattice parameter reported at 2033 K as 5.467 Å; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

DATA TABLE 256. THERMAL LINEAR EXPANSION OF URANIUM DICARBIDE UC_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*,†	
1340	0.000
1526	0.335
1624	0.513
1726	0.671
1849	0.987
1906	1.461
1934	1.559
1950	1.500
1997	1.915
2011	2.053
2023	2.132
2032	2.073
2051	2.112
CURVE 2*,†	
1350	0.000
1530	-0.016
1629	-0.068
1737	-0.132
1851	-0.247
1913	-0.198
1941	-0.330
1957	-0.297
1999	-0.445
2006	-0.313
2025	-0.611
2037	-0.776
2051	-0.908
CURVE 3*,†	
2033	0.000
2037	-0.145
2054	-0.145
2063	-0.236
2131	-0.054
2150	-0.072
2166	0.018
2212	0.273
2260	0.273
2319	0.637
2399	0.637
2417	0.746
2591	1.129

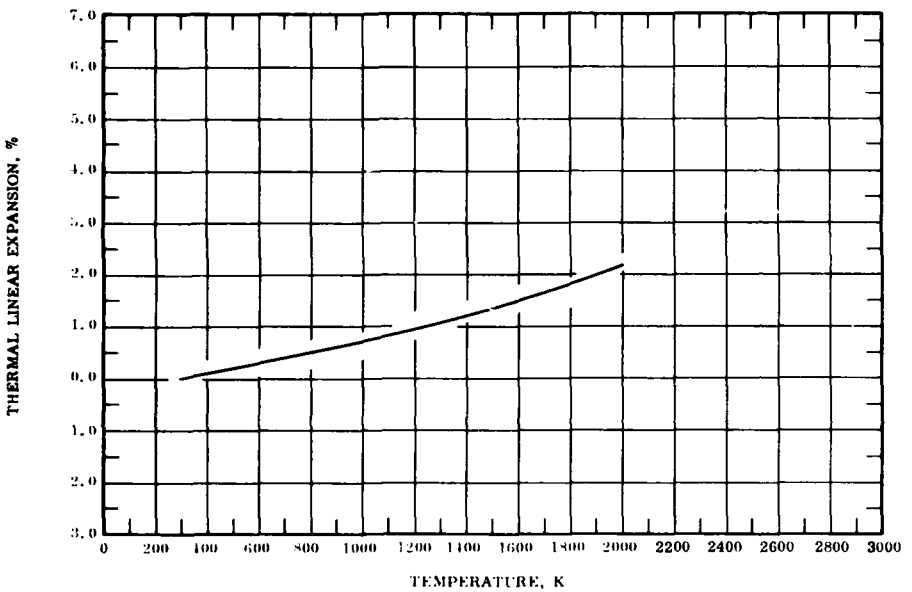
T	$\Delta L/L_0$
CURVE 4	
293	0.00
408	0.25
481	0.33
566	0.53
659	0.62
713	0.79
803	0.87
885	1.09
966	1.17
1036	1.32
1123	1.40
1133	1.44*
1148	1.43
1208	1.51
CURVE 5	
293	0.00*
408	0.20
481	0.14
566	0.33
659	0.37
713	0.50
803	0.53
885	0.81
966	0.74
1036	0.86
1123	0.88
1133	0.83
1148	0.84
1208	0.89
CURVE 6*,†	
2097	0.000
2156	-0.056
2279	0.242
2298	0.187
2331	0.392
CURVE 7*,†	
2085	0.000
2104	0.000
2120	0.018

T	$\Delta L/L_0$
CURVE 7 (cont.)*,†	
2154	0.111
2211	0.278
2228	0.185
2228	0.278
2255	0.352
2277	0.334
2289	0.371
2412	0.594
CURVE 8*,†	
2048	0.000
2075	0.036
2085	0.110
2129	0.147
2171	0.294
2185	0.294
2203	0.387
2305	0.645
2353	0.645
2376	0.663
CURVE 9*,†	
2136	0.000
2178	0.073
2226	0.237
2292	0.383
2314	0.383
CURVE 10*,†	
2033	-0.000
2047	0.091
2077	0.164
2138	0.274
2160	0.329
2176	0.347
2192	0.384
2219	0.420
2250	0.512
2264	0.512
2312	0.621
2312	0.676

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

FIGURE AND TABLE NO. 257R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF URANIUM SESQUICARBIDE U_2C_3



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	9.9
300	0.007	9.9
400	0.108	10.0
500	0.208	10.0
600	0.307	10.0
700	0.406	10.1
800	0.506	10.2
900	0.609	10.5
1000	0.715	10.8
1200	0.941	11.8
1400	1.192	13.2
1600	1.476	15.2
1800	1.801	17.4
2000	2.174	20.0

REMARKS

The recommended values are based on the data for pure samples. [redacted] These values are considered accurate to within ±3%. [redacted] These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.316 + 1.147 \times 10^{-3} T - 2.807 \times 10^{-7} T^2 + 1.649 \times 10^{-10} T^3$$

The tabulated values for the coefficient of thermal expansion are primarily calculated by differentiating the above equation and are considered accurate to about ± 5%.

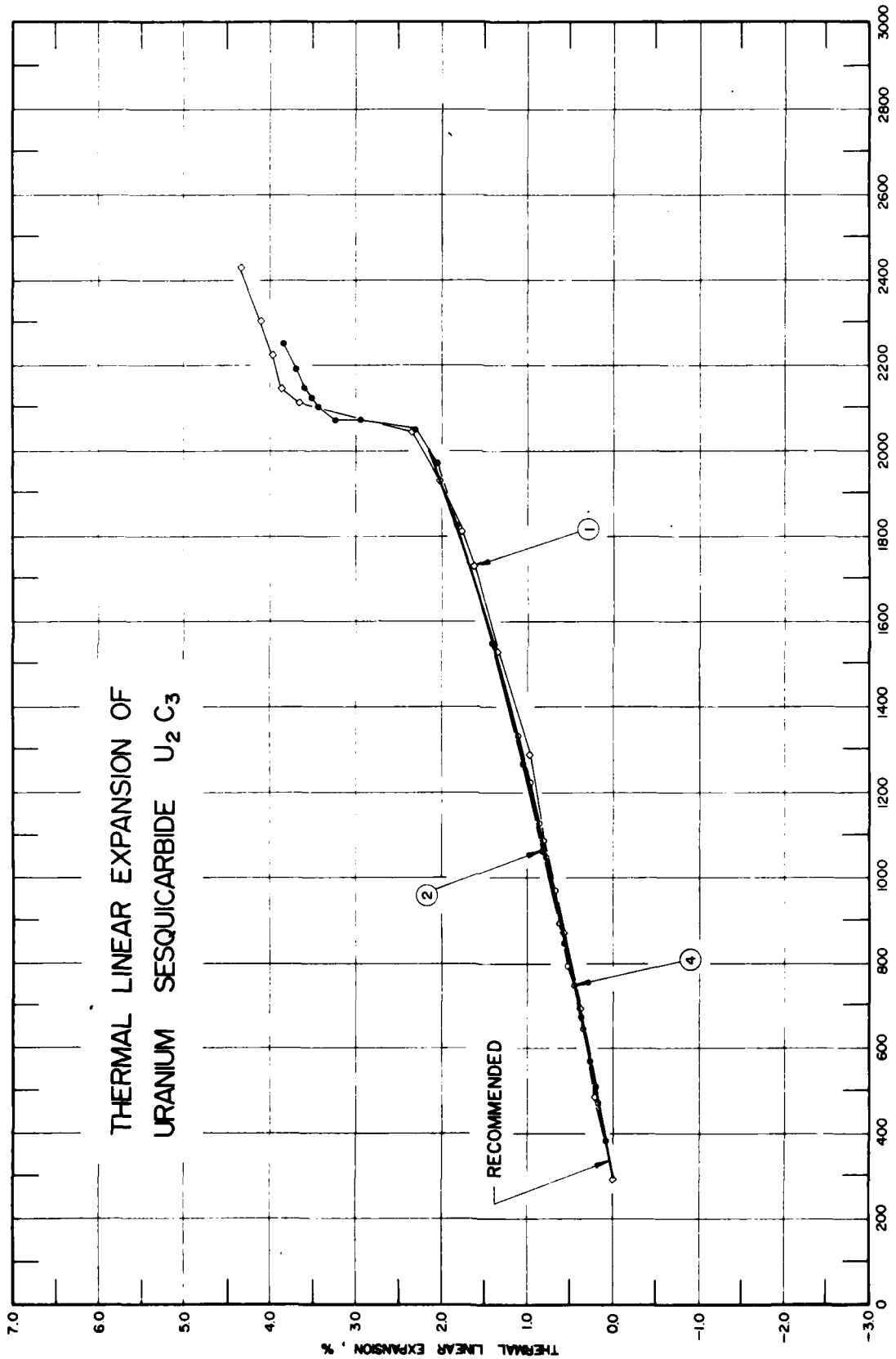

THERMAL LINEAR EXPANSION OF
URANIUM SESQUICARBIDE U_2C_3
RECOMMENDED
1
2
4
THERMAL LINEAR EXPANSION , %
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
TEMPERATURE , K

FIGURE 257

SPECIFICATION TABLE 257. THERMAL LINEAR EXPANSION OF URANIUM SESQUICARBIDE U_2C_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	711	Mendez-Penalosa, R. and Taylor, R.E.	1964	T	293-2433		7.02 C; specimen dimensions, 3/8 in. diameter by 5 in. long; specimen prepared by arc-casting a mixture of UC and UC_2 with a total carbon content of 7.0 wt.% and heat-treating for 6 hr in vacuum of 10^{-5} mm Hg at 1873 K stoichiometric U_2C_3; heating rate approximately 4 C per min.; specimen showed a permanent expansion of about 0.5%; author stated that pronounced expansion at about 2053 K was thought to be caused by U_2C_3 - UC + UC_2; reported error ±2%.
2	711	Mendez-Penalosa, R. and Taylor, R.E.	1964	T	293-2253		7.04 C; same as the above specimen except used heating rate of approximately 0.4 C per min. above 2023 K.
3*	712	Bowman, A.L., Arnold, G.P., Witteman, W.G., and Wallace, T.C.	1965	X	1453-2020		Specimen prepared from high-purity uranium and graphite by arc-melting and grinding to a powder; specimen decomposed at 2003 K; lattice parameter reported at 1453 K as 8.167 Å; this curve is here reported using 1453 K as reference temperature at which $\Delta L/L_0 = 0$.
4	713	Street, R.S. and Rand, M.H.	1963	X	293-1332		Specimen prepared by arc melting pure elements; annealed 24 hr at 1673 K; x-ray analysis detected only body-centered-cubic phase; lattice parameter reported at 293 K as 8.0882 Å.
5*	714	Benz, R. and Farr, J.D.	1971	X	2372-2432	$UC_{1.5}$	10 mm diameter cylinder, alloy of uranium and carbon, were melted and crushed to powders; mixture was cold-pressed into a cylinder annealed for 2 min. at 2373 K - reground into a powder with prestle, process was repeated three times, the specimen weighed 1.3 g; up to 1873 K specimen was heated in a high vacuum; at higher temperatures it was heated in a 5 Torr argon atmosphere; lattice parameter reported at 2372 K as 5.312 Å; this curve is here reported using 2373 K as reference temperature at which $\Delta L/L_0$.
6*	714	Benz, R. and Farr, J.D.	1971	X	2181-2325	$UC_{1.57}$	Similar to the above except slightly different composition; lattice parameter reported at 2181 K as 5.343 Å; this curve is here reported using 2181 K as reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

DATA TABLE 257. THERMAL LINEAR EXPANSION OF URANIUM SESQUICARBIDE U_2C_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.00
489	0.21
693	0.39
873	0.59
1089	0.81
1245	0.99
1531	1.35
1729	1.63
1817	1.78
1937	2.01
2041	2.35
2113	3.66
2145	3.86
2161	3.88*
2225	3.99
2301	4.10
2433	4.36
CURVE 2	
293	0.00*
509	0.20
677	0.38
849	0.58
1065	0.81
1269	1.06
1549	1.41
1829	1.82
1973	2.08
2041	2.31
2073	2.98
2073	3.01*
2073	3.15*
2075	3.23
2103	3.45
2121	3.52
2133	3.56*
2145	3.60
2197	3.70
2253	3.85
CURVE 3*, †	
1453	0.000
1518	0.110
1522	0.282
1531	0.140
1567	0.147
1567	0.331
1580	0.342
1600	0.185
1621	0.282
1628	0.380
1652	0.245
1671	0.270
1672	0.392
1701	0.331
1721	0.355
1756	0.404
1756	0.465
1794	0.502
1804	0.551
1839	0.404
1839	0.538
1841	0.627
1872	0.478
1872	0.551
1900	0.722
1926	0.453
1947	0.625
1964	0.796
1973	0.820
1980	0.784
1980	0.637
1997	0.931
2020	0.845
CURVE 4	
293	0.000*
381	0.099
478	0.177
518	0.220*
571	0.283
642	0.349
671	0.385*
748	0.462
798	0.527
894	0.608
973	0.692
1053	0.786
1132	0.886
1225	0.999
1332	1.107
CURVE 5*, †	
2372	0.000
2406	0.000
2432	0.056
CURVE 6*, †	
2181	0.000
2218	0.093
2262	0.149
2262	0.224
2287	0.205
2287	0.262
2301	0.299
2310	0.224
2325	0.299

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

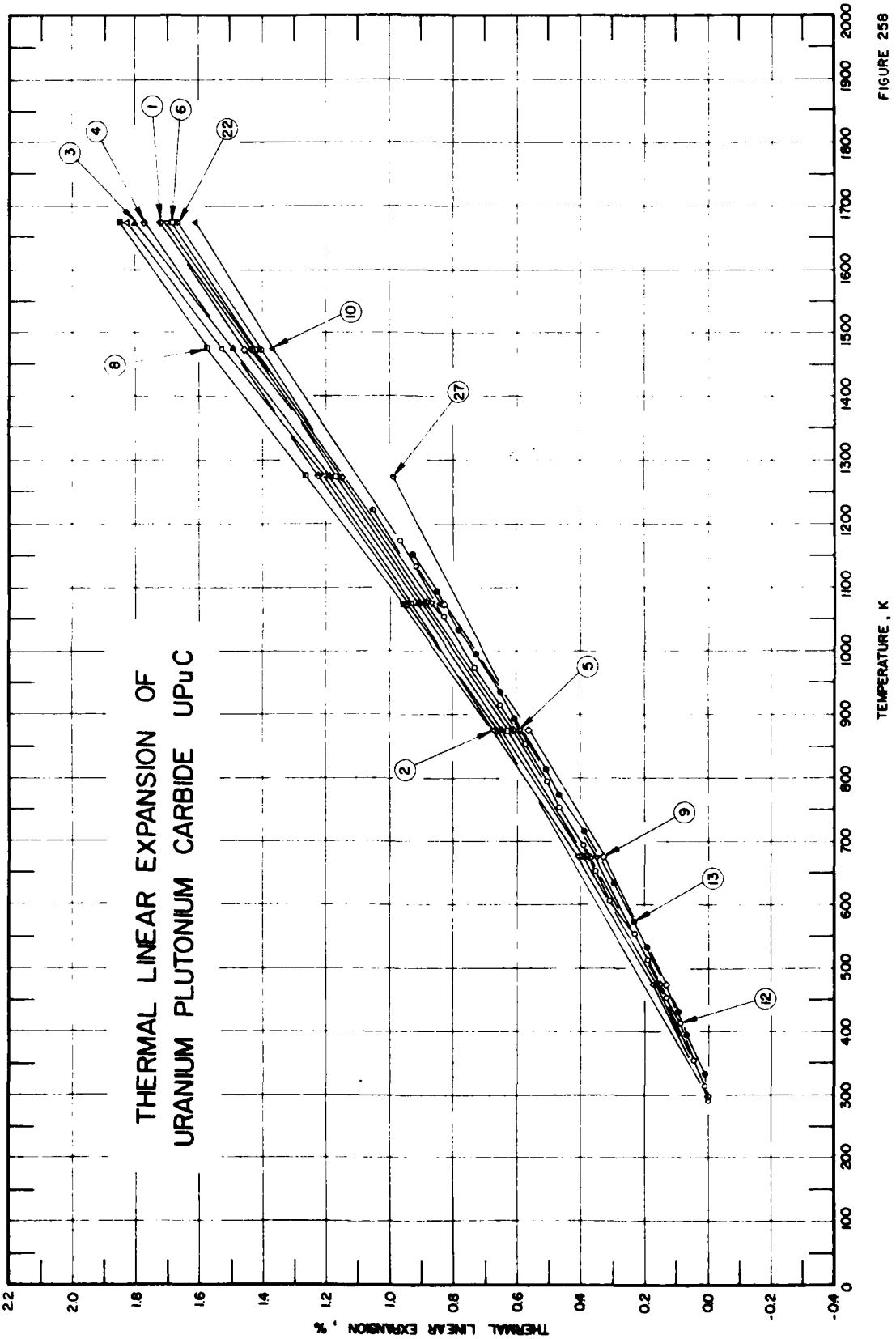

THERMAL LINEAR EXPANSION OF
URANIUM PLUTONIUM CARBIDE UPuC
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
4
5
6
8
9
10
12
13
22
27

FIGURE 258

SPECIFICATION TABLE 258. THERMAL LINEAR EXPANSION OF URANIUM PLUTONIUM CARBIDE UPuC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	698	Strasser, A., Stahl, D., Taylor, K., and Anderson, J.	1963	L	298-1673	$(U_{0.95}Pu_{0.05})C_{0.95}$	90.705 U, 4.67 C, 4.6 Pu, 0.0251 N_2; phase; powder presintered at 1823 K; final sintering at 2198 K for 1 hr; reported density 11.80 g/cm^3; first run; expansion measured by dial gauge with increasing temperature.
2	698	Strasser, A., et al.	1963	L	1673-298	$(U_{0.95}Pu_{0.05})C_{0.95}$	Same as the above specimen; expansion measured with decreasing temperature.
3	698	Strasser, A., et al.	1963	L	298-1673	$(U_{0.95}Pu_{0.05})C_{0.95}$	Same as the above specimen; expansion measured with differential transformer with increasing temperature.
4	698	Strasser, A., et al.	1963	L	1673-298	$(U_{0.95}Pu_{0.05})C_{0.95}$	Same as the above specimen; expansion measured with differential transformer with decreasing temperature.
5	698	Strasser, A., et al.	1963	L	298-1673	$(U_{0.95}Pu_{0.05})C_{0.95}$	Same as the above specimen; expansion measured with differential transformer with increasing temperature; second run.
6	698	Strasser, A., et al.	1963		298-1673	$(U_{0.95}Pu_{0.05})C_{0.98}$ + 0.1 Ni	90.0 U, 5.1 Pu, 4.77 C, 0.1 Ni, 0.0272 N_2; bar fabricated from powder of $(U_0(U_{0.95}Pu_{0.05})C_{0.98}$; sintered at 1823 K for 1 hr; density reported as 13.17 g-cm^{-3}; expansion measured by dial gauge; reported error ±5%.
7*	698	Strasser, A., et al.	1963		298-1673	$(U_{0.95}Pu_{0.05})C_{0.98}$ + 0.1 Ni	Same as the above specimen; expansion measured with linear variable differential transformer.
8	698	Strasser, A., et al.	1963		1673-298	$(U_{0.95}Pu_{0.05})C_{0.98}$ + 0.1 Ni	Same as the above specimen; expansion measured with dial gauge and decreasing temperature.
9	698	Strasser, A., et al.	1963		1673-298	$(U_{0.95}Pu_{0.05})C_{0.98}$ + 0.1 Ni	Same as the above specimen; expansion measured with decreasing temperature and linear variable differential transformer.
10	698	Strasser, A., et al.	1963		298-1673	$(U_{0.95}Pu_{0.05})C_{0.98}$ + 0.1 Ni	Same as the above specimen; expansion measured with increasing temperature and with dial gauge.
11*	698	Strasser, A., et al.	1963		298-1673	$(U_{0.95}Pu_{0.05})C_{0.98}$ + 0.1 Ni	Same as the above specimen; expansion measured with increasing temperature with linear variable differential temperature.
12	699	Ogard, A.E., Land, C.C., and Leary, J.A.	1962	L	293-1173	$U_{0.87}Pu_{0.13}C$	Solid solution; single phase; cylindrical specimen, 0.635 cm diameter x 2.54 cm long; expansion measured with increasing temperature; first run.
13	699	Ogard, A.E., et al.	1962	L	300-1173	$U_{0.87}Pu_{0.13}C$	Same as the above specimen; expansion measured with increasing temperature.
14*	700	Strasser, A., Stahl, D., Taylor, K., and Andersen, J.	1964		298-1673	$U_{0.95}Pu_{0.05}C_{0.98}$	Composition prior to testing 4.99 Pu, 4.67-4.69 C; after testing 5.01 Pu, 4.67 C, $U_{0.95}Pu_{0.05}C_{0.98}$; single phase monocarbide with some Widmanstätten structure; cylindrical specimen; 0.569 cm diameter x 0.546 cm long; mixed with 1/4 w/o Carbowax 6000 binder, cold pressed at 2100 kg-cm^{-2}; preheated to 973 K in open to crucible to vol binder; final sintering in closed Ta crucible at 2198 K for 1 hr; reported lattice parameter at 298 K as 4.9607 Å; expansion measured with linear variable differential transformer on first heating.
15*	700	Strasser, A., et al.	1964		298-1673	$U_{0.95}Pu_{0.05}C_{0.98}$	Same as the above specimen; expansion measured on first cooling.
16*	700	Strasser, A., et al.	1964		298-1673	$U_{0.95}Pu_{0.05}C_{0.98}$	Same as the above specimen; expansion measured on second heating.
17*	700	Strasser, A., et al.	1964		298-1673	$U_{0.95}Pu_{0.05}C_{0.98}$	Same as the above specimen; expansion measured with dial gauge and first heating.

* Not shown in figure.

SPECIFICATION TABLE 258. THERMAL LINEAR EXPANSION OF URANIUM PLUTONIUM CARBIDE UPuC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
18*	700	Strasser, A., Stahl, D., Taylor, K., and Andersen, J.	1964		298-1673	$U_{0.95}Pu_{0.05}C_{0.98}$	Same as the above specimen; expansion measured with dial gauge and first cooling.
19*	700	Strasser, A., et al.	1964		298-1673	$U_{0.95}Pu_{0.05}C_{0.98}$	Same as the above specimen; expansion measured with dial gauge and second heating.
20*	700	Strasser, A., et al.	1964		298-1673	$U_{0.95}Pu_{0.05}C_{0.98}$	Composition prior to testing 5.10 Pu, 4.81-4.77 C; after testing 4.95 Pu, 4.83 C; major phase UPuC; minor phase $(UPu)_2C_3$; contained sesquicarbide in monocarbide matrix; additional component 0.1 w/o Ni; powder blended with Ni powder in ballmill for 2 hr; mixed with C 1/4 w/o Carbowax 6000 binder, cold pressed at 2100 $kg\text{-}cm^{-2}$; cylindrical specimen 0.569 cm diameter x 0.546 cm long; preheated at 973 K in open to crucible to volatile binder; final sintering in closed Ta crucible at 1823 K for 0.5 hr; expansion measured with linear variable differential transformer with first heating; reported lattice parameter at 298 K as 4.962 Å.
21*	700	Strasser, A., et al.	1964		298-1673	$U_{0.95}Pu_{0.05}C_{0.98}$	Same as the above specimen; expansion measured with first cooling.
22	700	Strasser, A., et al.	1964		298-1673	$U_{0.95}Pu_{0.05}C_{0.98}$	Same as the above specimen; expansion measured with second heating.
23*	700	Strasser, A., et al.	1964		298-1073	$U_{0.95}Pu_{0.05}C_{0.98}$	Same as the above specimen; expansion measured with first heating and dial gauge.
24*	700	Strasser, A., et al.	1964		298-1673	$U_{0.95}Pu_{0.05}C_{0.98}$	Same as the above specimen; expansion measured with dial gauge and first cooling.
25*	700	Strasser, A., et al.	1964		298-1673	$U_{0.95}Ou_{0.05}C_{0.98}$	Same as the above specimen; expansion measured with dial gauge and second heating.
26*	701	Milet, C.A.	1968		293, 873	(U, Pu)C	Cast alloy specimen.
27	701	Milet, C.A.	1968		293, 1273	(U, Pu)C	Same as the above specimen.

* Not shown in figure.

DATA TABLE 258. THERMAL LINEAR EXPANSION OF URANIUM PLUTONIUM CARBIDE UPuC

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.0043
473	0.1562
673	0.3699
873	0.6138
1073	0.8878
1273	1.1451
1473	1.4378
1673	1.7231
CURVE 2	
1673	1.8336
1473	1.5324
1273	1.2041
1073	0.9348
873	0.6776
673	0.4061
473	0.1746
298	0.0048*
CURVE 3	
298	0.0047*
473	0.1696
673	0.3947
873	0.6430
1073	0.9115
1273	1.1942
1473	1.4969
1673	1.8060
CURVE 4	
1673	1.7780
1473	1.4965*
1273	1.2230
1073	0.9420
873	0.6655
673	0.3943*
473	0.1544*
298	0.0043*
CURVE 5	
298	0.0042*
473	0.1492*
673	0.3491
873	0.5964
1073	0.8721
1273	1.1546*
1473	1.4376*
1673	1.7091
CURVE 6	
298	0.0046*
473	0.1647*
673	0.3870*
873	0.6256
1073	0.8881*
1273	1.1746
1473	1.4263
1673	1.6821
CURVE 7*	
298	0.0043
473	0.1544
673	0.4130
873	0.6770
1073	0.9343
1273	1.1938
1473	1.4378
1673	1.6818
CURVE 8	
1673	1.8474
1473	1.5794
1273	1.2626
1073	0.9581
873	0.6776*
673	0.4061*
473	0.1748*
298	0.00486*
CURVE 9	
1673	1.7225*
1473	1.4608
1273	1.1445*
1073	0.8330
873	0.5633
673	0.3319
473	0.1359
298	0.0038
CURVE 10	
298	0.0042*
473	0.1494*
673	0.3492*
873	0.5849*
1073	0.8412
1273	1.1059*
1473	1.3672
1673	1.6129
CURVE 11	
298	0.0044
473	0.1597
673	0.3742
873	0.6254
1073	0.8802
1273	1.1452
1473	1.14027
1673	1.6682
CURVE 12	
293	0.000
314	0.015
333	0.030*
352	0.044
373	0.063*
393	0.075*
412	0.089
433	0.119*
452	0.134
473	0.153*
492	0.170*
512	0.192
531	0.208*
552	0.230
574	0.257*
593	0.277*
612	0.302
631	0.327*
653	0.347
674	0.369*
694	0.392
714	0.424*
734	0.448*
754	0.464
773	0.484*
793	0.508
813	0.529*
832	0.559*
854	0.579
874	0.600*
894	0.629*
913	0.657
934	0.681*
954	0.706*
973	0.734
992	0.753*
1011	0.782*
1033	0.803*
1051	0.828
1073	0.849*
1091	0.871*
1112	0.894*
1132	0.920
1150	0.946*
1173	0.969
CURVE 13	
300	0.000*
306	0.006*
313	0.005*
333	0.013
351	0.029*
371	0.050*
393	0.067
411	0.080*
433	0.095
452	0.118*
473	0.135*
512	0.176*
534	0.193
552	0.218*
573	0.239
592	0.258*
614	0.281*
632	0.298
653	0.318*
674	0.339*
694	0.361*
715	0.390
734	0.415*
754	0.439*
774	0.464
794	0.490*
812	0.510
834	0.535*
854	0.559*
874	0.580*
893	0.609
914	0.628*
935	0.655
953	0.679*
973	0.700*
994	0.732
1011	0.754*
1031	0.788
1052	0.810*
1072	0.832*
1091	0.855
1111	0.880*
1133	0.905*
1152	0.930
1173	0.961*
CURVE 14*	
298	0.005
473	0.170
673	0.395
873	0.644
1073	0.913
1273	1.196
1473	1.499
1673	1.808
CURVE 15*	
298	0.004
473	0.154
673	0.395
873	0.667
1073	0.944
1273	1.225
1473	1.499
1673	1.780
CURVE 16*	
298	0.004
473	0.149
673	0.350
873	0.597
1073	0.874
1273	1.156
1473	1.440
1673	1.711
CURVE 17*	
298	0.004
473	0.156
673	0.371
873	0.615
1073	0.889
1273	1.147
1473	1.440
1673	1.725
CURVE 18*	
298	0.005
473	0.175
673	0.407
873	0.679
1073	0.967
1273	1.254
1473	1.534
1673	1.835
CURVE 19*	
298	0.005
473	0.170
673	0.380
873	0.626
1073	0.905
1273	1.186
1673	1.739
CURVE 20*	
298	0.004
473	0.154
673	0.414
873	0.079

* Not shown in figure.

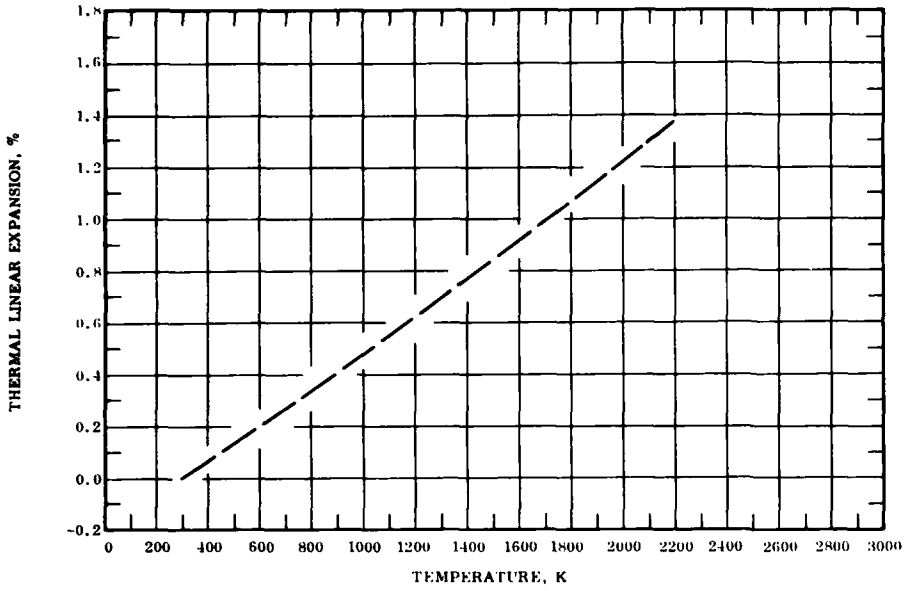
DATA TABLE 258. THERMAL LINEAR EXPANSION OF URANIUM PLUTONIUM CARBIDE UPuC (continued)

T	$\Delta L/L_0$
CURVE 20 (cont.)*	
1073	0.936
1273	1.196
1473	1.440
1673	1.684
CURVE 21*	
298	0.004
473	0.136
673	0.314
873	0.564
1073	0.835
1273	1.147
1473	1.463
1673	1.725
CURVE 22	
298	0.004
473	0.160
673	0.375
873	0.626
1073	0.881
1273	1.147
1473	1.404
1673	1.670
CURVE 23*	
298	0.005
473	0.165
673	0.388
873	0.626
1073	0.889
1273	1.176
1473	1.428
1673	1.684
CURVE 24*	
298	0.005
473	0.175
673	0.407
873	0.679
1073	0.959
1273	1.264
1473	1.581
1673	1.849

T	$\Delta L/L_0$
CURVE 25*	
298	0.004
473	0.149
673	0.350
873	0.586
1073	0.842
1273	1.107
1473	1.369
1673	1.615
CURVE 26*	
293	0.000
873	0.574
CURVE 27*	
293	0.000
1273	0.990

* Not shown in figure.

FIGURE AND TABLE NO. 259R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF VANADIUM CARBIDE VC



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	6.2
300	0.004	6.3
400	0.068	6.4
500	0.133	6.6
600	0.199	6.7
700	0.267	6.8
800	0.336	6.9
900	0.405	7.1
1000	0.476	7.2
1200	0.621	7.3
1400	0.768	7.4
1600	0.918	7.5
1800	1.068	7.5
2000	1.218	7.6
2200	1.368	7.6

REMARKS

The provisional values are based on the data for pure sample and are considered accurate to within ± 7% at temperatures below 1100 K and to within ± 10% above 1100 K. The disagreement of the provisional values with most of the earlier measurements are probably due to the sample variation. The provisional values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.176 + 5.718 \times 10^{-4}\, T + 9.785 \times 10^{-8}\, T^2 - 1.766 \times 10^{-11}\, T^3$$

The tabulated values of the coefficient of thermal expansion are primarily derived by differentiating the above equation and are accurate to within ± 10%.

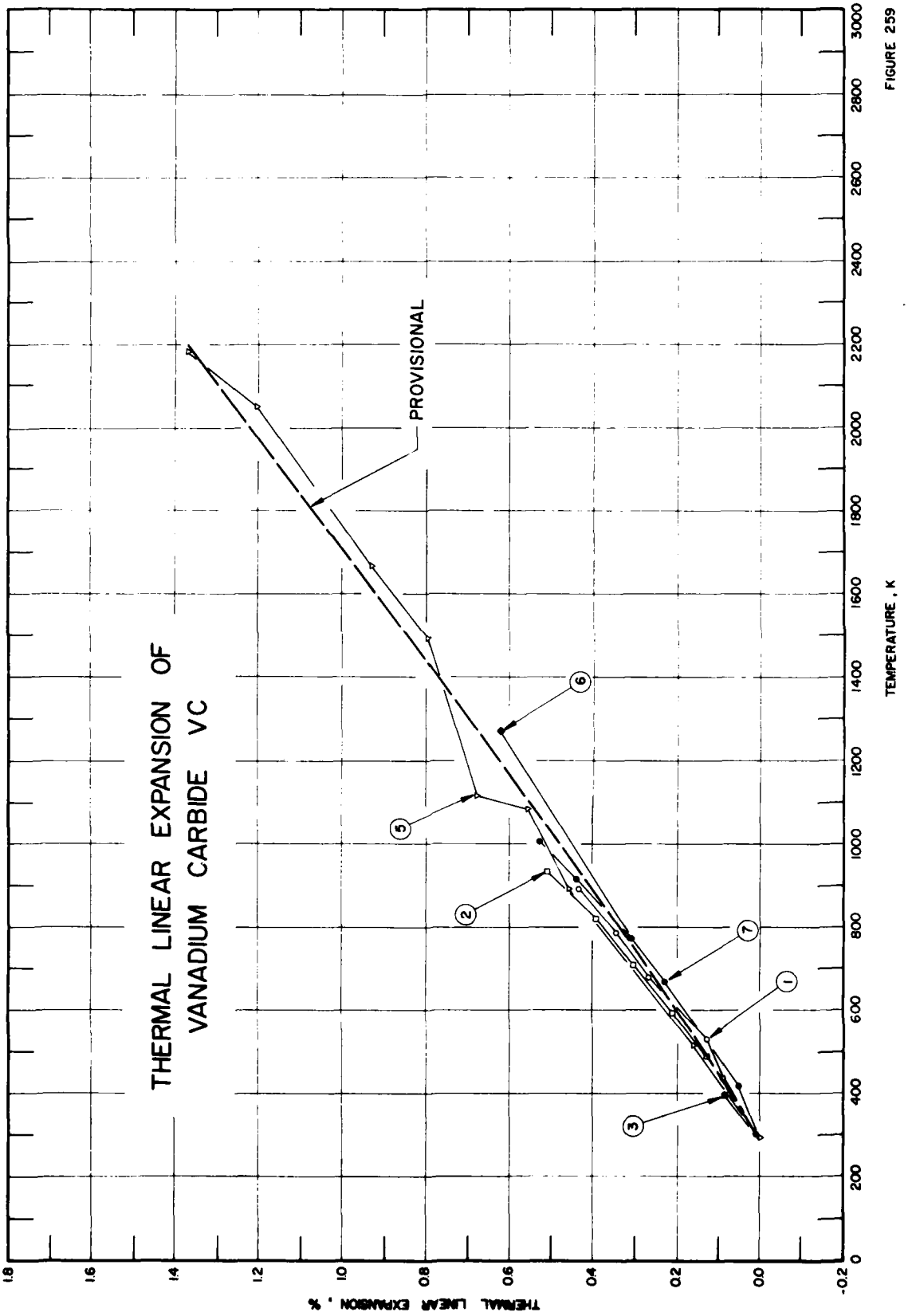

THERMAL LINEAR EXPANSION OF
VANADIUM CARBIDE VC
PROVISIONAL
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
1
2
3
5
6
7

FIGURE 259

SPECIFICATION TABLE 259. THERMAL LINEAR EXPANSION OF VANADIUM CARBIDE VC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	716	Storms, F.K. and Kempter, C.P.	1965	X	299-888	$VC_{0.89}$	5.79 free carbon, < 0.05 Fe, 0.027 O, and 0.014 N; prepared by heating mixture of the powdered items in vacuum; sintered plug reduced to -325 mesh; x-ray exposures made with nickel radiation; lattice parameter reported at 299 K as 4.1667 Å; 4.1662 Å at 293 K determined by graphical extrapolation.
2	716	Storms, F.K. and Kempter, C.P.	1965	X	298-933	$VC_{0.75}$	Similar to the above specimen; except 0.00 free carbon, 0.04 Fe, 0.04 N, and 0.003 O; lattice parameter reported at 298 K as 4.1283 Å; 4.1280 Å at 293 K determined by graphical extrapolation.
3	437	Frantsevich, I.N., Zhurakovskii, E.A., and Lyashchenko, A.B.	1967	X	293, 393		81.7 V, 18.2 C, and 19.0 theoretical content of metalloid; prepared from powder of compound by the vacuum sintering of pressed block.
4*	423	Brizes, W.F.	1968	T	1895-2611		High purity V rod inserted into graphite mold; diffusion annealed at ~473 K below carbide-carbon eutectic temperature; m.p. 3043 K; expansion measured in 15 μ Torr helium atmosphere; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
5	63	Pears, C.D. and Oglesby, S.	1962	L	293-2405		81.0 V, 18.6 C, 0.5 N; initial length 5.92 cm, final length 6.38 cm; Carborundum Company; elements found by semi-quantitative emission spectrography before exposure 0.7 Fe, after exposure 80.8 V, 18.4 C, and 0.3 N; hot pressed; run no. E6; melting point on post inspection; density in g cm^{-3} before exposure 5.42 by ASTM method B311-58, 5.45 by wax-coating specimen, 5.47 by immersion in gleve, after exposure 5.0 by ASTM method, 5.0 by wax-coating specimen, and 5.1 by immersion in gyleve; measured in helium atmsophere; authors observed melting on post inspection; data given by author ignored above 2405 K.
6	599	Samsonov, G.V., Grebenkina, V.G., and Klimenko, V.C.	1971	L	293, 1273		Reported error 1.5%.
7	658	Stuart, H. and Ridley, N.	1970	X	293-1002		Dimensions, rod; 0.555 cm diameter x 1.5875 long; specimen extracted from high purity alloys from BISRA as hot rolled bars; bar was austenitized at 1373 K for 30 min. in purified argon atmosphere; quenched in water; then tempered at 973 K for 2000 hrs; lattice parameter reported at 293 K as 4.1598 Å.

* Not shown in figure.

DATA TABLE 259. THERMAL LINEAR EXPANSION OF VANADIUM CARBIDE VC

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
299	0.012
436	0.091
527	0.151
676	0.266
781	0.345
888	0.436
CURVE 2	
298	0.007*
483	0.130
589	0.210
706	0.305
819	0.392
933	0.508
CURVE 3	
293	0.000*
393	0.084
CURVE 4*, †, ‡	
1895	0.000
2064	0.371
2355	0.3776
2611	0.5934
CURVE 5	
293	0.00
517	0.16
898	0.47
1088	0.55
1117	0.68
1494	0.80
1662	0.93
2045	1.20
2189	1.38
2405	2.18*
CURVE 6	
293	0.000*
1273	0.620
CURVE 7	
293	0.000*
416	0.053
524	0.123*
664	0.224
770	0.308
908	0.438
1002	0.526

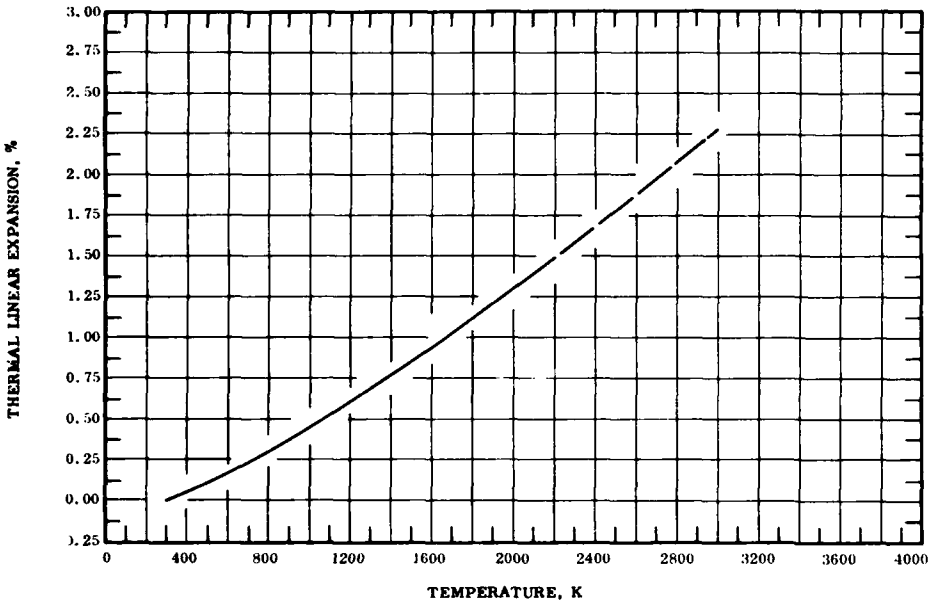
DATA TABLE 259. COEFFICIENT OF THERMAL LINEAR EXPANSION OF VANADIUM CARBIDE VC

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 4*, †, ‡	
1895	8.02
2064	8.20
2355	8.33
2611	8.53

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 260R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE ZrC



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	4.0
300	0.003	4.0
400	0.049	5.0
500	0.101	5.6
600	0.161	6.2
700	0.225	6.7
800	0.295	7.1
900	0.369	7.4
1000	0.446	7.6
1200	0.607	8.1
1400	0.771	8.5
1600	0.941	8.8
1800	1.120	9.0
2000	1.302	9.3
2200	1.488	9.5
2400	1.678†	9.7
2600	1.872†	9.9
2800	2.068†	10.2
3000	2.269†	10.2

† Provisional values.

REMARKS

The recommended values are based on the data for pure samples and are considered accurate to within ± 5% at temperatures below 2200 K and to within ± 10% above 2200 K. The disagreement of the recommended values especially above 1400 K with the experimental data is probably due to sample variation. The recommended values are represented approximately by the following equations:

$$\Delta L/L_0 = -0.080 + 1.280 \times 10^{-4}\, T + 5.372 \times 10^{-7}\, T^2 - 1.392 \times 10^{-10}\, T^3 \qquad (293\text{–}1500\ K)$$

$$\Delta L/L_0 = -0.358 + 7.355 \times 10^{-4}\, T + 4.859 \times 10^{-8}\, T^2 - 6.327 \times 10^{-13}\, T^3 \qquad (1500\text{–}3000\ K)$$

The tabulated values of the coefficient of thermal expansion are primarily derived from the selected experimental data and those obtained by differentiation of the above equations. These values are considered accurate to about ± 10%.

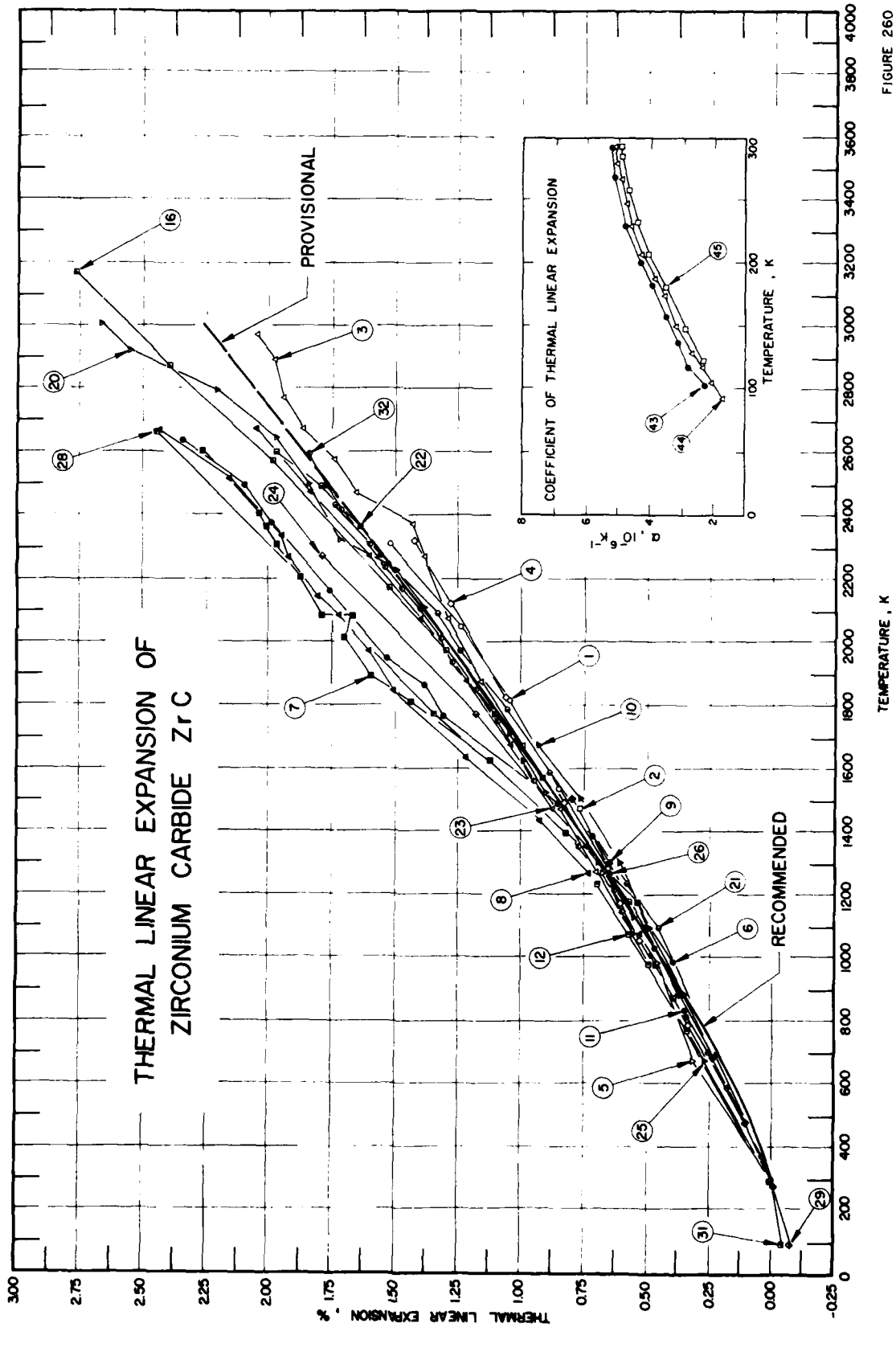

THERMAL LINEAR EXPANSION OF
ZIRCONIUM CARBIDE ZrC
PROVISIONAL
RECOMMENDED
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K

FIGURE 260

SPECIFICATION TABLE 260. THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE ZrC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	420	Houska, C.R.	1963	X	298-2313	$ZrC_{0.95}$	87.69 Zr, 11.0 combined carbon, 0.26 N, 0.22 B, 0.22 Ti, 0.18 Fe, 0.14 free carbon, and 0.11 O; sample pressed at 0.1266 kg cm^{-2} from powders less than 6 microns; heated in vacuum to 1723 K for 1 hr; CuKα radiation used; expansion measured from (511/333) and (440) plane; reported error > 2%; zero-point correction of 0.003% determined by graphical extrapolation.
2	421	Frantsevich, I.N., Zhurakovskii, E.A., and Lyashchenko, A.B.	1967	X	293, 1473		Specimen prepared from powder by the vacuum sintering of pressed block.
3	422	Richardson, J.H.	1965	X	293-2971		99.6 Zr, 0.094 Cl, 0.050 O, 0.032 Mg, 0.018 Fe, 0.007 Hf, 0.0064 Cr, < 0.002 Ti, and 0.001 Ni; prepared by vacuum are casting; slurry made of 0.1 g of powdered carbide with 0.5 ml of binder solution (Duso cement and acetone 1:20 by volume); uniform thin layer of slurry applied to central portion of major surface on graphite heating element, and allowed to dry for 5 min.; CuKβ radiation and (111) reflections used.
4	423	Brizes, W.F.	1968	T	293-2321		High purity Zr rod inserted into graphite mold; diffusion annealed at ~ 473 K below carbide-carbon eutectic temperature; m.p. 3693 K; expansion measured in 15 μ helium atmosphere.
5	424	Elliott, R.O. and Kempter, C.P.	1958	X	296-1267		93.8 pure, 0.5 free carbon, specimen from D.H. Sebell at Los Alamas Scientific Laboratories; 325 mesh powder sealed in silica capillary; lattice parameter reported at 296.2 K as 4.6828 Å; 4.6827 Å at 293.2 K determined by graphical extrapolation.
6	425	Miccioli, B.R. and Shaffer, P.T.B.	1964	T	991-2638		88.43 Zr, 11.27 total C and 0.26 free C; rectangular bar; 3.2 mm x 3.2 mm x 7.1 mm long; prepared from reactor grade 99.83 pure ZrO_2 and Thermatomic carbon; cold-pressed into briquets using polyvinyl alcohol as binder before reaction sintering in argon atmosphere; density 5.99 g cm^{-3}; reported error 0.02%.
7	425	Miccioli, B.R. and Shaffer, P.T.B.	1964	T	1175-2603		The above specimen; expansion measured on run no. 2; zero-point correction is ±0.000%.
8	425	Miccioli, B.R. and Shaffer, P.T.B.	1964	T	1267-2671		The above specimen; expansion measured on run no. 3.
9	10	Mauer, F.A. and Bolz, L.H.	1955	X	273-1509		88.0 pure, 1-10 Hf, 4.0 Si, < 0.1 each Al, Cr, Fe, Ti, < 0.01 any other impurity; 1.30 free carbon; commercial powder; expansion measured in helium atmosphere; zero-point correction of -0.012% determined by graphical interpolation.
10	10	Mauer, F.A. and Bolz, L.H.	1957	X	273-1673		88.0 pure, 1-10 Hf, < 1.0 Si, < 0.1 each Al, Cr, Fe, Ti; < 0.01 any other impurity; 12.72 C (theoretically 11.64); 1.3 free C; commercial powder; expansion measured in vacuum; zero-point correction of -0.012% determined by graphical interpolation.
11	145	Gangler, J.J.	1950	I	366-826		Specimen hot pressed; thru pyramids 4 to 5 mm long constituted a single specimen; expansion measured with heating rate 4 C per min.
12	12	Graham, S.A.	1950	T	293-1233		Commercial powder ball milled to ~ 5 μ, hot pressed into bar and ground to 1.3 1.3 x 0.14 in. square; expansion measured in argon atmosphere on run no. 1; reported error < 5.0%.
13*	12	Graham, S.A.	1950	T	1233-293		The above specimen; expansion measured with decreasing temperature.

* Not shown in figure.

SPECIFICATION TABLE 260. THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE ZrC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
14*	12	Graham, S.A.	1950	T	293-1233		The above specimen; expansion measured with increasing temperature on run no. 2; reported error 5%.
15*	12	Graham, S.A.	1950	T	1233-293		The above specimen; expansion measured with decreasing temperature.
16	426	Paderno, Yu.B., Dudnik, E.M., Andreevna, T.V., Barantseva, L.G., Yupko, V.L.	1965	T	293-2904		98.37 pure; hot pressed specimen 15 to 18 mm long, 8 mm diameter; expansion measured in atmosphere of 10^{-2} mm Hg pressure.
17*	318	Neel, D.S., Pears, C.D., and Oglesby, S., Jr.	1962	L	293-2360		Before exposure 88.5 Zr, 11.0 C, 0.5 N, and 0.1 others, after exposure 89.3 Zr, 18.8 C, and 0.5 N; initial length 6.4287 cm; obtained from General Electric Company; pressed and sintered; density at 298 K before exposure 6.27 g cm^{-3} by ASTM method B311-58, 6.28 g cm^{-3} by wax-coating specimen, 6.33 g cm^{-3} by immersion in xylene, after exposure 6.24 g cm^{-3} by ASTM method, 6.27 g cm^{-3} by wax-coating specimen, and 6.28 g cm^{-3} by immersion in xylene; specimen broken on post inspection; run SRI-1326 after expansion measurement; reported error 2%.
18*	427	Taylor, R.E. and Nakata, M.M.	1963		293-2728	Sample A	87.85 Zr, 12.14 C, impurities < 0.7; rectangular bar: 6.4 x 6.4 x 127 mm; hot pressed at about 2023 K as received from Carborundum Corporation; density 6.39 g cm^{-3}.
19*	427	Taylor, R.E. and Nakata, M.M.	1963		2520-293	Sample A	The above specimen; expansion measured with decreasing temperature; zero-point correction of -0.0908%.
20	427	Taylor, R.E. and Nakata, M.M.	1963		293-3003	Sample A	The above specimen; expansion measured with increasing temperature on second run.
21	427	Taylor, R.E. and Nakata, M.M.	1963		293-2430	Sample B	87.85 Zr, 12.14 C, impurities < 0.7; annealed at 2073 K; density 6.39 g cm^{-3}; measured with increasing temperatures.
22	427	Taylor, R.E. and Nakata, M.M.	1963		295-2600	Sample B	The above specimen; expansion measured on second run.
23	428	Leipold, M.H. and Nielson, L.H.	1963	L	298-2673		Bal. Zr, 9.7 C (1.4 free), 1 Hf, 0.94 N, 0.18 O, 0.01-0.1 Fe, 0.01-0.1 Ti, 0.001-0.01 Co, 0.001-0.01 Ni, 0.001-0.1 Cr, < 0.001 Si, < 0.001 Al, < 0.001 Sn, and < 0.001 V; hot pressed by the vendar and heat treated for 1 hr at 1450 K at JPL; density before heat-treated 6.19-6.5 g cm^{-3}.
24	429	Shaffer, P.T.B. and Mark, S.D.	1963		293-2273		Expansion measured in inert atmosphere with pressure of approximately 2.54 cm water above atmospheric pressure.
25	430	Hasselman, D.P.H. and Shaffer, P.T.B.	1962		298-1623	Composite OB	91.2 vol.% ZrC; spectrographic analysis of ZrC powder: 0.1-0.5 Fe, 0.01-0.05 Cr, Ca, and 0.005-0.01 B, Si, Ti; from New Products Branch, the Carborundum Co. in form of -325 mesh powder; specimen prepared in rotary mill hot pressed at 2523 K and 140 kg cm^{-2} into 11.43 cm diameter x 10.2 cm long pieces and ground; porosity 8.8%; bulk density 6.11 g cm^{-3}, density of ZrC calculated from crystal structure data 6.70 g cm^{-3}; expansion measured perpendicular to hot pressing direction.
26	431	Lepie, M.P.	1964	L	273, 1273		Hot pressed specimen.
27*	432	Miccioli, B.R. and Julien, H.P.	1965	T	300-1623		Hot pressed specimen; density 6.11 g cm^{-3}; expansion measured perpendicular to pressing direction.

* Not shown in figure.

SPECIFICATION TABLE 260. THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE ZrC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
28	432	Miccioli, B.R. and Julien, H.P.	1965	T	300-2663		Similar to the above specimen; density 5.99 g cm^{-3}; expansion measured parallel to pressing direction.
29	433	Krikorian, N.H. and Wallace, T.C.	1963	X	83, 299	$ZrC_{0.97}$	0.3 percent carbon deficient powder; specimen obtained from Union Carbide Metals Co.; lattice parameter reported at 299 K as 4.6986 Å; 4.6985 Å at 293 K determined by graphical interpolation.
30*	433	Krikorian, N.H. and Wallace, T.C.	1963	X	83, 299	$ZrC_{0.95}$	0.5 percent carbon deficient powder; prepared by reacting reactor grade Zr and spectroscopic grade graphite 1 to 2 hr at 2473 K in vacuum of 10^{-5} to 10^{-6} Torr; lattice parameter reported at 299 K as 4.7025 Å; 4.7024 Å at 293 K determined by graphical interpolation.
31	433	Krikorian, N.H. and Wallace, T.C.	1963	X	83, 299	$ZrC_{0.80}$	2.0 percent carbon deficient; similar to the above specimen; lattice parameter reported at 299 K as 4.6980 Å; 4.6979 Å at 293 K determined by graphical interpolation.
32	442	Bowman, A.L., Krikorian, N.H., and Nereson, N.G.	1972		293-2595		0.0100 N and 0.0545 O; powdered specimen placed in parallel-sided neutron diffraction graphite holders, heat to 2473 K for 4-6 hr in vacuum ($\sim 5 \times 10^{-6}$ Torr) prior to measurement; expansion measured by high-temperature neutron diffraction; lattice parameter reported at 293 K as 4.6991 Å.
33*	443	Bernstein, H.	1964	X	1073, 1773		Powder specimen sifted through 200 mesh screen and deposited as a thin slurry directly on the tantalum heater strips (heater strips annealed at 1773 K for several hours prior to use); expansion measured under pressure of 1-2 x 10^{-5} mm Hg; lattice parameter reported at 293 K as 4.695 Å; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
34*	658	Ridley, N. and Stuart, H.	1970	X	293-1220		87.6 Zr, 11.5 C (total), 1.0 C (free), 34 N, 0.23 O, 0.2 Fe, < 0.02 each Ni and Ti; powdered specimen placed in 0.5 mm diameter quartz capillary tube ~ 4.0 cm long.
35*	682	Zil'berberg, V.G., Kutsenok, T.G., and Shariuker, S.Yu	1970	L	293-1251		Dimensions: 3 mm diameter x 5 mm long; plasma sprayed specimen; thickness of sprayed material was 4-4.5 mm, density reported as 5.85-5.95 g cm^{-3}, porosity 11-13% expansion measured in argon atmosphere, parallel to grain; zero-point correction is -0.14% at 293 K determined by graphical extrapolation; reported error 2.5%.
36*	682	Zil'berberg, V.G., et al.	1970	L	293-1183		The above specimen; expansion measured perpendicular to grain -0.14%; zero-point correction is -0.14% at 293 K determined by graphical extrapolation.
37*	660	Samsonov, G.V. and Naumenko, V.Ya.	1969	L	298, 1273	$ZrC_{1.0}$	88.00 Zr, 11.81 C (total); cut from 8 x 12-15 mm rod into 2.5 x 2.5 x 12-14 cm bar made at 160 kg cm^2 and 2373 K - 2873 K for 15 min; annealed at 2273-2473 K for 8 hr at 1.2×10^{-4} mm Hg; measurements made in argon atmosphere; reported error 2.0%.
38*	660	Samsonov, G.V. and Naumenko, V.Ya.	1969	L	298, 1273	$ZrC_{0.9}$	Similar to the above specimen except 89.20 Zr and 10.52 C (total).
39*	660	Samsonov, G.V. and Naumenko, V.Ya.	1969	L	298, 1273	$ZrC_{0.8}$	Similar to the above specimen except 90.34 Zr and 9.51 C (total).

* Not shown in figure.

SPECIFICATION TABLE 260. THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE ZrC (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
40*	660	Samsonov, G.V. and Naumenko, V.Ya.	1969	L	298, 1273	$ZrC_{0.75}$	Similar to the above specimen except 91.21 Zr and 8.75 C (total).
41*	660	Samsonov, G.V. and Naumenko, V.Ya.	1969	L	298, 1273	$ZrC_{0.65}$	Similar to the above specimen except 91.67 Zr and 7.75 C (total).
42*	599	Samsonov, G.V., Grebenking, V.G., and Klimenko, V.G.	1971	L	293, 1273		Reported error 1.5%.
43*	717	Borukhovich, A.S., Matveenko, I.I., Zaimulin, Yu.G., Alyamovskii, S.I., and Gel'd, P.V.	1970	L	102-310	$ZrC_{0.97}$	Rectangular bar; specimen 4 x 5 x 25 mm; sintered in high vacuum and porosity was 10-20%; reported error 3-4%.
			1970	L	93-359	$ZrC_{0.79}$	Similar to the above specimen except rectangular bar; 1 x 4 x 25 mm.
44*	717	Borukhovich, A.S., et al.	1970	L	122-347	$ZrC_{0.58}$	Similar to the above specimen except rectangular bar; 4 x 5 x 25 mm.
45*	717	Borukhovich, A.S., et al.					

* Not shown in figure.

DATA TABLE 260. THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE ZrC

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.003
1027	0.477
1284	0.669
1540	0.855
1818	1.043
2045	1.243
2313	1.523
CURVE 2	
293	0.00
1473	0.77
CURVE 3	
293	0.000*
1273	0.715
1473	0.847
1673	0.996
1873	1.168
2073	1.296
2273	1.399
2373	1.431
2473	1.658
2572	1.741
2673	1.870
2770	1.941
2873	1.977
2971	2.057
CURVE 4‡	
293	0.000*
782	0.342
1054	0.532
1168	0.613
1492	0.832
1823	1.059
2124	1.282
2321	1.428
CURVE 5	
296	0.0021*
671	0.3224
CURVE 5 (cont.)	
975	0.4676
1267	0.6812
CURVE 6	
991	0.402
1284	0.659*
1384	0.724
1493	0.861
1764	1.316
1861	1.397
1947	1.529
2162	1.763
2379	1.991
2500	2.107
2638	2.343
CURVE 7	
1175	0.546
1395	0.828
1629	1.128
1810	1.447
1890	1.590
2015	1.703
2081	1.673
2081	1.790
2201	1.877
2316	1.974
2367	2.018
2403	2.046
2603	2.273
CURVE 8	
1267	0.735
1439	0.930
1639	1.224
1842	1.512
1970	1.603
2082	1.725
2149	1.811
2271	1.927
2340	1.959
2520	2.170
2671	2.434
CURVE 9	
273	-0.012
298	0.003*
479	0.114
685	0.244
891	0.376
1097	0.516
1303	0.655
1509	0.802
CURVE 10	
273	-0.012*
298	0.003*
479	0.112*
685	0.235*
891	0.354
1097	0.491
1303	0.618
1509	0.770
1673	0.934
CURVE 11	
366	0.04
479	0.11*
588	0.18
700	0.26
811	0.35
826	0.36
CURVE 12	
293	0.000*
773	0.345
973	0.496
1073	0.577
1233	0.705
CURVE 13*	
1233	0.695
1073	0.577
973	0.496
773	0.345
293	0.000
CURVE 14*	
293	0.000
773	0.331
973	0.489
1073	0.577
1233	0.714
CURVE 15*	
1233	0.705
1073	0.585
973	0.503
773	0.341
293	0.000
CURVE 16	
293	0.000
773	0.324*
873	0.394
973	0.466
1173	0.575
1273	0.685*
1573	0.922
1773	1.100
1973	1.294
2173	1.523
2573	1.984
2873	2.399
3173	2.768
CURVE 17*	
293	0.000
609	0.145
751	0.207
889	0.266
1099	0.368
1191	0.420
1321	0.487
1438	0.559
1544	0.611
1656	0.669
1722	0.714
1819	0.765
1937	0.794
CURVE 17 (cont.)*	
2068	0.838
2178	0.885
2226	0.905
2313	0.930
2360	0.956
CURVE 18*	
293	0.000
1088	0.686
1353	0.943
1568	1.135
1730	1.245
1911	1.404
2079	1.575
2279	1.750
2550	1.995
2728	2.370
CURVE 19*	
2520	2.6292
2140	2.2692
1868	1.9992
1640	1.8332
293	0.0000
CURVE 20	
293	0.000*
1126	0.558
1303	0.700
1523	0.913
1713	1.045
1877	1.172*
2112	1.345
2223	1.495
2373	1.720
2500	1.850
2643	1.975
2793	2.210
2923	2.560
3003	2.670
CURVE 21	
293	0.000*
1093	0.454
1238	0.583
1583	0.892
1783	1.055
1970	1.245
2093	1.340
2277	1.560
2430	1.740
CURVE 22	
295	0.000*
1320	0.635
2367	1.645
2492	1.795
2600	1.975
CURVE 23	
298	0.003*
673	0.233*
873	0.375*
1073	0.527
1278	0.683*
1353	0.746
1473	0.877
1673	1.041
1873	1.220
2075	1.410
2273	1.608
2473	1.833
2673	2.059
CURVE 24	
293	0.000*
1273	0.679*
1773	1.181
2273	1.792
CURVE 25	
298	0.003*
473	0.103*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 260. THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE ZrC (continued)

T	$\Delta L/L_0$
CURVE 25 (cont.)	
673	0.249
873	0.403*
1073	0.558
1273	0.718*
1473	0.879*
1623	0.996
CURVE 26	
273	-0.013*
1273	0.657
CURVE 27*	
300	0.005
1273	0.718
1623	0.996
CURVE 28	
300	0.005*
1273	0.677*
1773	1.354
2273	1.934*
2663	2.450
CURVE 29	
83	-0.0723
299	0.0021*
CURVE 30*	
83	-0.0786
299	0.0021
CURVE 31	
83	-0.0383
299	0.0021*
CURVE 32	
293	0.000*
1143	0.608
1209	0.664
1273	0.717*
1351	0.775
1474	0.873*
1561	0.949
1636	1.008*
1755	1.096
1847	1.179
1934	1.273
2010	1.341
2110	1.409
2176	1.483
2236	1.536
2313	1.600
2416	1.713
2497	1.773
2595	1.849
CURVE 33*,†	
1073	0.000
1773	0.590
CURVE 34*	
293	0.000
398	0.049
490	0.089
580	0.139
676	0.194
767	0.254
852	0.309
956	0.381
1043	0.454
1127	0.528
1220	0.612
CURVE 35*	
293	0.000
391	0.056
518	0.155
648	0.261
720	0.317
799	0.398
891	0.463
1039	0.557
1138	0.660
1197	0.705
1251	0.746
CURVE 36*	
293	0.000
409	0.096
449	0.115
526	0.219
562	0.259
618	0.329
656	0.399
749	0.509
861	0.650
986	0.799
1072	0.877
1183	0.937
CURVE 37*	
298	0.016
1273	0.657
CURVE 38*	
298	0.003
1273	0.662
CURVE 39*	
298	0.003
1273	0.666
CURVE 40*	
298	0.003
1273	0.676
CURVE 41*	
298	0.003
1273	0.675
CURVE 42*	
293	0.000
1273	0.700
CURVE 43*	
102	-0.079
123	-0.073
137	-0.069
156	-0.063
177	-0.055
200	-0.045
238	-0.028
269	-0.012
293	0.000
298	0.003
321	0.015
348	0.030
370	0.042
CURVE 44*	
93	-0.076
105	-0.074
117	-0.071
130	-0.068
150	-0.062
170	-0.055
188	-0.048
206	-0.041
230	-0.031
247	-0.023
266	-0.013
280	.007
293	0.000
312	0.010
325	0.017
337	0.023
359	0.035
CURVE 45*	
122	-0.067
148	-0.060
176	-0.051
207	-0.039
233	-0.028
258	-0.017
285	-0.004
293	0.000
301	0.004
322	0.015
347	0.028

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 260. COEFFICIENT OF THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE ZrC

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 4‡	
293	6.8
782	6.9*
1054	7.0*
1168	7.0*
1492	6.5*
1823	7.2*
2124	7.5*
2321	7.3*
CURVE 43	
102	2.28
123	2.81
137	3.19
156	3.57
177	3.98
200	4.34
230	4.80
269	5.09
293	5.21
298	5.28
321	5.39*
348	5.46*
370	5.51*
CURVE 44	
93	1.77
105	2.02
117	2.37
130	2.70
150	3.20
170	3.57
188	3.86
206	4.23
230	4.60
247	4.75
266	4.87
280	4.99
293	5.10
312	5.17*
325	5.31*
337	5.35*
359	5.42*
CURVE 45	
122	2.35
148	2.98
176	3.52
207	4.04
233	4.40
258	4.66
285	4.88
293	4.95
301	5.02*
322	5.16*
347	5.22*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 261. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CARBIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	436	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969		293,1273	Ce_2C_3	Cerium carbide; specimen synthesized by fusing the elements in an arc furnace.
2*	656	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	373-1173	Ce_2C_3	Cerium carbide; no details given.
3*	435	Atoji, M.	1967	X	5,300	CeC_2	Cerium dicarbide; 0.5 to 1.5 uncombined graphite; powdered sample; average particle size ~15 μ; expansion measured parallel to a-axis.
4*	435	Atoji, M.	1967	X	5,300	CeC_2	Cerium dicarbide; the above specimen except expansion measured parallel to c-axis.
5*	655, 656	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	373,1173	CeC_2	Cerium dicarbide; no details given.
6*	655, 656	Paderno, Yu. B., et al.	1969	L	293-1343	CeC_2	Cerium dicarbide; zero-point correction is 0.033% determined by graphical interpolation.
7*	656	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	373,1173	DyC_2	Dysprosium carbide; no details given.
8*	656	Paderno, Yu. B., et al.	1969	L	293-1447	DyC_2	Dysprosium carbide; zero-point correction is 0.074% at 293 K.
9*	656	Paderno, Yu. B., et al.	1969	L	373,1173	ErC_2	Erbium carbide; no details given.
10*	656	Paderno, Yu. B., et al.	1969	L	293-1327	ErC_2	Erbium carbide; zero-point correction is 0.074% at 293 K.
11*	656	Paderno, Yu. B., et al.	1969	L	373,1173	GdC_2	Gadolinium carbide; no details given.
12*	656	Paderno, Yu. B., et al.	1969	L	293-1345	GdC_2	Gadolinium carbide; zero-point correction is 0.059% determined by graphical interpolation.
13*	435	Atoji, M.	1967	X	5,300	HoC_2	Holmium carbide; 2 percent impurities; powdered sample; average particle size ~10 μ in; expansion measured parallel to a-axis.
14*	435	Atoji, M.	1967	X	5,300	HoC_2	Holmium carbide; the above specimen; expansion measured along c-axis.
15*	677	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	373,1123	LaC_2	Lanthanum carbide; no details given.
16*	677	Paderno, Yu. B., et al.	1969	L	293-1339	LaC_2	Lanthanum carbide; zero-point correction is 0.021% at 293 K.
17*	436	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969		293,1273	La_2C_3	Dilanthanum tricarbide; specimen synthesized by fusing the elements in arc furnace.
18*	677	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	373-1173	La_2C_3	Dilanthanum tricarbide; no details given.
19*	429	Shaffer, P. J. B. and Mark, S. D.	1963	L	293-2273	MoC	Molybdenum carbide; expansion measured in inert atmosphere ~1100 torr.
20*	435	Atoji, M.	1967	X	5,300	NdC_2	Neodymium carbide; 0.5 to 1.5 uncombined graphite; powdered sample; average particle size ~10 μm; expansion measured parallel to a-axis.
21*	435	Atoji, M.	1967	X	5,300	NdC_2	Neodymium carbide; the above specimen; expansion measured parallel to c-axis.
22*	656	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	373,1173	NdC_2	Neodymium carbide; no details given.
23*	656	Paderno, Yu. B., et al.	1969	L	293-1335	NdC_2	Neodymium carbide; zero-point correction is 0.021% at 293 K.

* No figure given.

SPECIFICATION TABLE 261. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CARBIDES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
24*	436	Paderno, Yu. B., Yupko, V. L., and Makerenko, G. N.	1969		293, 1273	Nd_2C_3	Dineodymium tricarbide; specimen synthesized from the elements by fusion in arc furnace.
25*	656	Paderno, Yu. B., Yupko, V. L., and Makerenko, G. N.	1969	L	373, 1173	Nd_2C_3	Dineodymium tricarbide; no details given.
26*	660	Samsonov, G. V. and Navmenko, V. Ya.	1969	L	298, 1273	Nb_2C	Diniobium carbide; 93.52 Nb, 6.00 C (total); cut from 8 mm diameter x 12-15 mm long rods into a 2.5 x 2.5 x 12-14 mm bar; made by sintering process at 160 kg-cm^{-2} at 2373-2873 K for 15 min; annealed at 2273-2473 K for 8 hr at 1.2 x 10^{-4} mm Hg; expansion measured in argon atmosphere; reported error is 2.0%.
27*	435	Atoji, M.	1967	X	5, 300	PrC_2	Praseodymium carbide; 0.5 to 1.5 uncombined graphite; powdered sample; average particle size ~10 μm; expansion measured parallel to a-axis.
28*	435	Atoji, M.	1967	X	5, 300	PrC_2	Praseodymium carbide; the above specimen; expansion measured along c-axis.
29*	656	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	373, 1173	PrC_2	Praseodymium carbide; no details given.
30*	655, 656	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	293-1351	PrC_2	Praseodymium carbide; zero-point correction is 0.038% at 293 K.
31*	684	Pallmer, P. G.	1962	X	298-1053	Pu_2C_3	Plutonium sesquicarbide; cubic structure; specimen prepared by heating a mixture of plutonium hydride and carbon and crushing the sintered pellet; percent expansion calculated from lattice parameters; measured by x-ray diffraction.
32*	683	Green, J. L. and Leary, J. A.	1970	X	293-1888	Pu_2C_3	Plutonium sesquicarbide; 86.7 Pu, 10.25 C, 0.04 O, <0.1 Ta, < 0.03 Zr, <0.01 Nb, <0.0075 W, 0.0060 Cu, 0.005 each Fe, Ta, 0.0001 Sn, <0.0001 each B, Bi, Mn; specimen prepared by a 600 mesh powder, moistened with outgassed high purity toluene to a heater strip which was outgassed by heating to 1873 K in Ar; specimen planed to a uniform thickness, sintered in Ar at 2173 K for 2.5 hr; lattice parameter reported at 293 K as 8.1319 ± 0.0002 Å.
33*	656	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	373, 1173	SmC_2	Samarium dicarbide; no details given.
34*	655	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	293-1332	SmC_2	Samarium dicarbide; zero-point correction is -0.021% at 293 K.
35*	660	Samsonov, G. V. and Navmenko, V. Ya.	1969	L	298, 1273	Ta_2C	Ditantalum carbide; 96.08 Ta_2, 3.21 C (total); cut from 8 mm x 12 to 15 mm long rod into 2.5 mm x 2.5 mm x 12 to 14 mm bar; made by sintering process at 160 kg-cm^{-2} at 2373-2873 K for 15 min; annealed at 2275 K for 8 hr; expansion measured in argon atmosphere; reported error is 2.0%.
36*	435	Atoji, M.	1967	X	5, 300	TbC_2	Terbium dicarbide; 0.5 to 1.5 uncombined graphite; powdered sample; average particle size ~10 μm; expansion measured parallel along a-axis.
37*	435	Atoji, M.	1967	X	5, 300	TbC_2	Terbium dicarbide; the above specimen; expansion measured along c-axis.
38*	656	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	373, 1173	TbC_2	Terbium dicarbide; no details given.

* No figure given.

SPECIFICATION TABLE 261. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CARBIDES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
39*	655	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	293-1343	TbC_2	Terbium dicarbide; zero-point correction is 0.074% at 293 K.
40*	72	Aronson, S., Cisney, R., and Gingerich, K. A.	1967	X	1175-1732	$ThC_{0.84}$	Thorium carbide; sample prepared directly from elements by heating mixtures of Th and graphite powders to 1873-1973 K for 2 hr; handled and stored in helium glove box; observed melting point 2898 K; lattice parameter reported at 293 K as 5.326 Å.
41*	670	Lorenzelli, R. and de Dieuleveult, L.	1968	X	293-1277	ThC	Thorium carbide; specimen formed from thorium dihydride and carbon; sintered at 1773 K 5 x 10^{-6} torr vacuum; lattice parameter reported at 293 K as 5.3329 Å.
42*	716	Storms, F. K. and Kempter, C. P.	1965	X	298-876	V_2C	Vanadium carbide; prepared by heating mixture of the powdered elements in vacuum; sintered slug reduced to 325 mesh; x-ray exposure made by nickel radiations; expansion measured along a-axis; lattice parameter reported at 299 K as 2.9018 Å; 2.9017 Å at 293 K determined by graphical extrapolation.
43*	716	Storms, F. K. and Kempter, C. P.	1965	X	298-876	V_2C	Vanadium carbide; the above specimen; expansion measured along c-axis; lattice parameter reported at 299 K as 4.5756 Å; 4.5753 Å at 293 K determined by graphical extrapolation.
44*	656	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	373, 1173	YC_2	Yttrium carbide; no details given.
45*	655	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	293-1448	YC_2	Yttrium carbide; zero-point correction is -0.049% at 293 K.
46*	436	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969		293, 1273	Y_2C_3	Yttrium sesquicarbide; specimen synthesized from the elements in arc furnace; reported error is ±3.0%.
47*	656	Paderno, Yu. B., Yupko, V. L., and Makarenko, G. N.	1969	L	373, 1173	Y_2C_3	Yttrium sesquicarbide; no details given.

* No figure given.

DATA TABLE 261. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CARBIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.00
1273	1.44
CURVE 2*	
373	0.117
1173	1.293
CURVE 3*	
5	-0.086
300	0.002
CURVE 4*	
5	-0.173
300	0.004*
CURVE 5*	
373	0.108
1173	1.188
CURVE 6*	
293	0.000
389	0.084
435	0.117
535	0.243
584	0.295
634	0.348
735	0.448
788	0.488
835	0.546
932	0.646
987	0.711
1039	0.781
1088	0.856
1143	0.947
1190	1.044
1245	1.124
1343	1.367
CURVE 7*	
373	0.091
1173	1.003

T	$\Delta L/L_0$
CURVE 8*	
293	0.000
438	0.126
483	0.180
538	0.254
586	0.315
691	0.428
735	0.473
789	0.534
842	0.596
886	0.642
943	0.723
985	0.738
1040	0.797
1092	0.854
1141	0.935
1192	1.004
1245	1.063
1294	1.124
1345	1.159
1394	1.253
1447	1.388
CURVE 9*	
373	0.099
1173	1.091
CURVE 10*	
293	0.000
437	0.116
487	0.150
537	0.264
587	0.335
634	0.382
682	0.441
734	0.501
786	0.569
840	0.637
937	0.711
994	0.846
1045	0.903
1094	0.971
1136	1.019
1195	1.146
1255	1.243
1298	1.327

T	$\Delta L/L_0$
CURVE 10 (cont.)*	
1327	1.387
CURVE 11*	
373	0.108
1173	1.188
CURVE 12*	
293	0.000
390	0.139
437	0.181
486	0.236
542	0.299
586	0.357
637	0.413
689	0.478
734	0.521
788	0.593
837	0.655
891	0.723
936	0.787
988	0.857
1043	0.914
1091	0.976
1142	1.047
1194	1.112
1242	1.189
1268	1.195
1291	1.241
1321	1.298
1345	1.371
CURVE 13*	
5	-0.259
300	0.006
CURVE 14*	
5	-0.115
300	0.003
CURVE 15*	
373	0.095
1173	1.047

T	$\Delta L/L_0$
CURVE 16*	
293	0.000
338	0.050
486	0.232
536	0.281
584	0.325
634	0.408
685	0.461
736	0.523
788	0.575
835	0.641
889	0.709
942	0.763
992	0.821
1038	0.862
1089	0.933
1142	1.009
1196	1.085
1244	1.158
1294	1.262
1339	1.392
CURVE 17*	
293	0.000
1273	1.401
CURVE 18*	
373	0.116
1173	1.284
CURVE 19*	
293	0.000
1273	0.556
1773	1.218
2273	2.277
CURVE 20*	
5	-0.086
300	0.002
CURVE 21*	
5	-0.230
300	0.006

T	$\Delta L/L_0$
CURVE 22*	
373	0.074
1173	0.818
CURVE 23*	
293	0.000
434	0.151
485	0.187
681	0.395
736	0.481
783	0.510
834	0.567
887	0.611
935	0.611
988	0.674
1040	0.695
1090	0.756
1137	0.794
1187	0.857
1190	0.885
1240	0.888
1288	0.990
1335	1.098
CURVE 24*	
293	0.00
1273	1.32
CURVE 25*	
373	0.108
1173	1.188
CURVE 26*	
298	0.004
1273	0.690
CURVE 27*	
5	-0.086
300	0.002

T	$\Delta L/L_0$
CURVE 28*	
5	-0.144
300	0.003
CURVE 29*	
373	0.096
1173	1.064
CURVE 30*	
293	0.000
388	0.078
536	0.282
640	0.403
687	0.457
736	0.512
788	0.559
839	0.623
889	0.671
936	0.732
990	0.803
1035	0.853
1140	0.988
1192	1.015
1243	1.162
1283	1.287
1351	1.390
CURVE 31*	
298	0.007
673	0.548
873	0.795
1053	1.127
CURVE 32*	
293	0.000
1073	1.119
1273	1.476
1473	1.808
1688	2.152
1888	2.546

* No figure given.

DATA TABLE 261. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CARBIDES (continued)

T	$\Delta L/L_0$
CURVE 33*	
373	0.091
1173	1.002
CURVE 34*	
293	0.000
941	0.617
987	0.675
1035	0.739
1097	0.817
1141	0.872
1243	1.041
1296	1.145
1332	1.275
CURVE 35*	
298	0.003
1273	0.710
CURVE 36*	
5	-0.317
300	0.008
CURVE 37*	
5	-0.173
300	0.004
CURVE 38*	
373	0.081
1173	0.891
CURVE 39*	
293	0.000
405	0.107
449	0.124
497	0.169
542	0.228
592	0.283
694	0.386
838	0.534
892	0.588
939	0.666
990	0.723
1042	0.769

T	$\Delta L/L_0$
CURVE 39 (cont.)*	
1091	0.826
1141	0.871
1194	0.946
1247	0.995
1296	1.075
1324	1.124
1343	1.190
CURVE 40*	
1175	0.642
1215	0.624
1362	0.794
1444	0.828
1531	0.902
1601	0.983
1732	1.079
CURVE 41*	
293	0.000
299	0.000
374	0.054
674	0.236
873	0.330
973	0.413
1025	0.481
1074	0.447
1126	0.560
1174	0.654
1227	0.724
1277	0.804
CURVE 42*	
299	0.003
466	0.072
533	0.148
668	0.220
804	0.310
876	0.379
CURVE 43*	
299	0.006
466	0.137
533	0.251
668	0.382
804	0.539

T	$\Delta L/L_0$
CURVE 43 (cont.)*	
876	0.633
CURVE 44*	
373	0.073
1173	0.809
CURVE 45*	
293	0.000
484	0.186
533	0.240
583	0.275
1038	0.673
1091	0.718
1140	0.774
1247	0.951
1349	0.962
1403	1.049
1448	1.155
CURVE 46*	
293	0.000
1273	1.009
CURVE 47*	
373	0.082
1173	0.902

* No figure given.

SPECIFICATION TABLE 262. THERMAL LINEAR EXPANSION OF TANTALUM CARBIDE + TUNGSTEN CARBIDE TaC + WC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	446	Panov, V.S. and Meerson, G.A.	1968	L	291,693		90.0 TaC, 10.0 WC; specimen 16 mm diameter x 5 to 10 mm high; carbides mixed 8 hr in ball mill, calcined 2 hr at 2473 to 2573 K in hydrogen atmosphere, milled 96 hr in alcohol; prepared by hot pressing at 2473 K to 2573 K under 250 kg cm^{-2}; homogenized 7.5 hr at 2273 K and annealed 48 hr at 1723 K; solid solution verified by x-ray analysis.
2*	446	Panov, V.S. and Meerson, G.A.	1968	L	291,693		92.0 TaC, 8.0 WC; similar to the above specimen.
3*	446	Panov, V.S. and Meerson, G.A.	1968	L	291,693		98.0 WC, 2.0 TaC; similar to the above specimen.
4*	446	Panov, V.S. and Meerson, G.A.	1968	L	291,693		95.0 WC, 5.0 TaC; similar to the above specimen.
5*	446	Panov, V.S. and Meerson, G.A.	1968	L	291,693		50.0^{+} WC, 50.0^{-} TaC; similar to the above specimen.

DATA TABLE 262. THERMAL LINEAR EXPANSION OF TANTALUM CARBIDE + TUNGSTEN CARBIDE TaC + WC

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
291	-0.001
693	0.264
CURVE 2*	
291	-0.001
693	0.272
CURVE 3*	
291	-0.001
693	0.176
CURVE 4*	
291	-0.001
693	0.182
CURVE 5*	
291	-0.001
693	0.226

* No figure given.

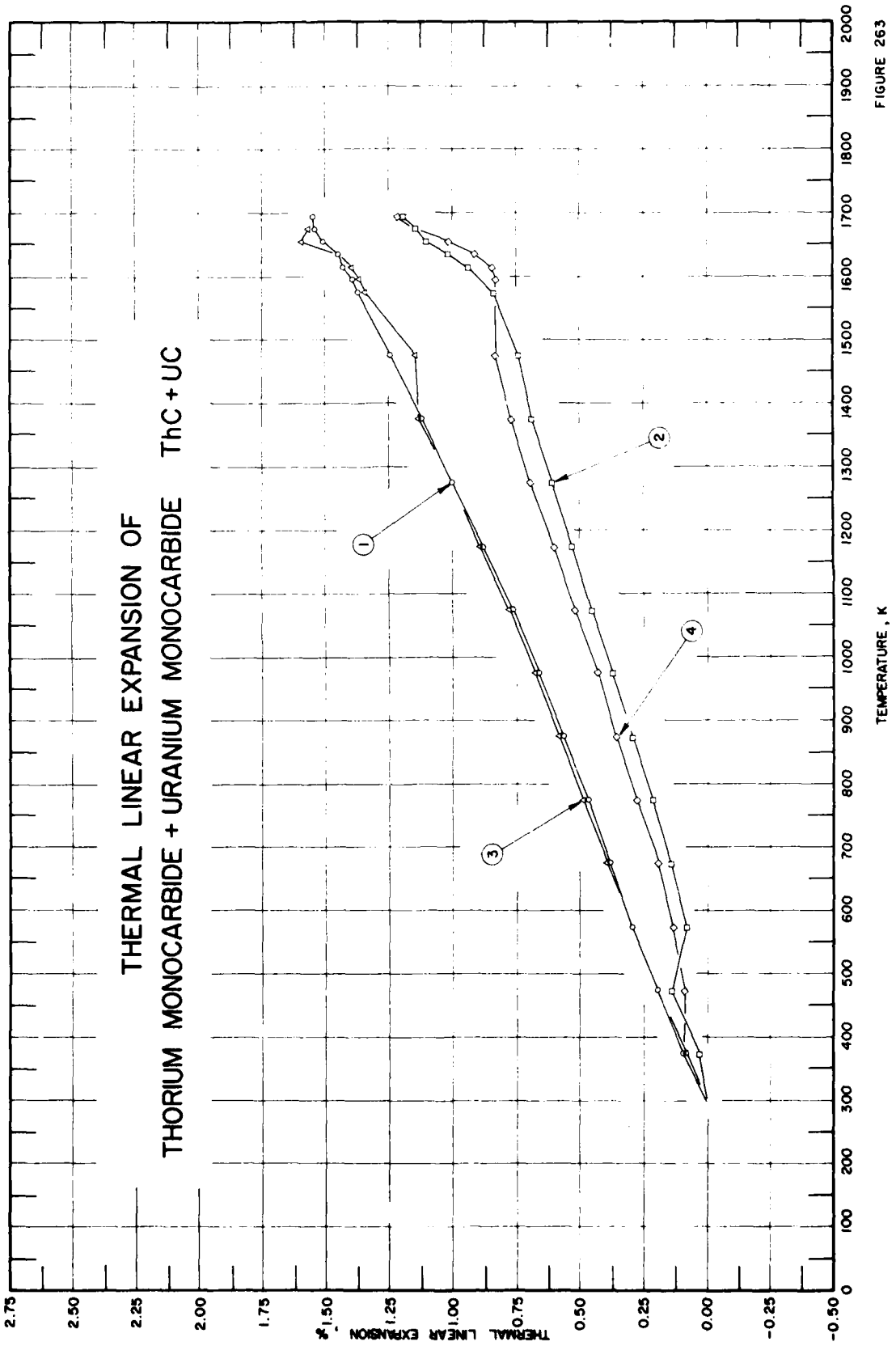

THERMAL LINEAR EXPANSION OF
THORIUM MONOCARBIDE + URANIUM MONOCARBIDE ThC + UC
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
4

FIGURE 263

SPECIFICATION TABLE 263. THERMAL LINEAR EXPANSION OF THORIUM MONOCARBIDE + URANIUM MONOCARBIDE ThC + UC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	441	Marchal, M., Accary, A., and Saclay, C. E. A.	1963	N	373-1693		50 ThC, 50 UC; expansion measured with increasing temperature at 150 C/hr.
2	441	Marchal, M., et al.	1963	N	1693-373		Same as the above specimen; expansion measured with decreasing temperature at 150 C/hr.
3	441	Marchal, M., et al.	1963	N	373-1673		Same as the above specimen; expansion measured with increasing temperature.
4	441	Marchal, M., et al.	1963	N	1693-373		Same as the above specimen; expansion measured with decreasing temperature.

DATA TABLE 263. THERMAL LINEAR EXPANSION OF THORIUM MONOCARBIDE + URANIUM MONOCARBIDE ThC + UC

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
373	0.095
473	0.197
573	0.290
673	0.377
773	0.468
873	0.562
973	0.661
1073	0.764
1173	0.876
1273	1.000
1373	1.122
1473	1.242
1573	1.372
1593	1.398
1613	1.428
1633	1.450
1653	1.507

CURVE 1 (cont.)

T	$\Delta L/L_0$
1673	1.542
1693	1.550

CURVE 2

T	$\Delta L/L_0$
1693	1.195
1673	1.144
1653	1.102
1633	1.017
1613	0.937
1573	0.838
1473	0.742
1373	0.689
1273	0.611
1173	0.529
1073	0.453
973	0.370

CURVE 2 (cont.)

T	$\Delta L/L_0$
873	0.291
773	0.215
673	0.142
573	0.081
473	0.137
373	0.029

CURVE 3

T	$\Delta L/L_0$
373	0.085
473	0.194*
573	0.294*
673	0.388
773	0.485
873	0.577
973	0.673
1073	0.776

CURVE 3 (cont.)

T	$\Delta L/L_0$
1173	0.884
1273	1.004*
1373	1.129
1473	1.144
1573	1.345
1593	1.369
1613	1.399
1633	1.442*
1653	1.598
1673	1.571

CURVE 4

T	$\Delta L/L_0$
1693	1.216
1673	1.140*
1653	1.017
1633	0.914

CURVE 4 (cont.)

T	$\Delta L/L_0$
1613	0.843
1593	0.827
1573	0.843*
1473	0.831
1373	0.773
1273	0.691
1173	0.599
1073	0.519
973	0.432
873	0.354
773	0.275
673	0.192
573	0.134
473	0.088
373	0.095*

* Not shown in figure.

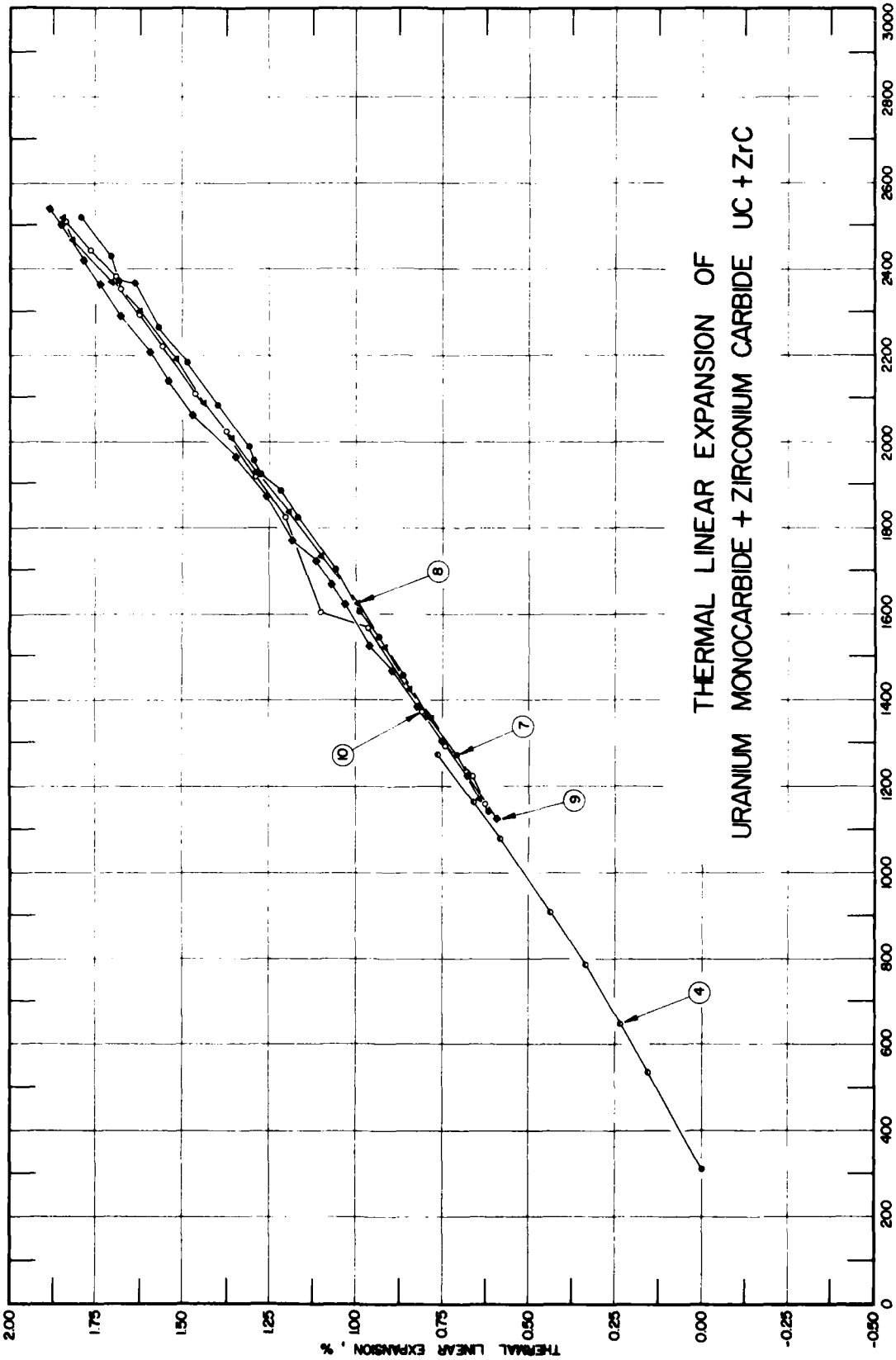

THERMAL LINEAR EXPANSION OF
URANIUM MONOCARBIDE + ZIRCONIUM CARBIDE UC + ZrC
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
8
7
9
10
4

FIGURE 264

SPECIFICATION TABLE 264. THERMAL LINEAR EXPANSION OF URANIUM MONOCARBIDE + ZIRCONIUM CARBIDE UC + ZrC

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	702	Bocker, S. and Boncher, R.	1969	L	293-1273	Composition No. 7	Phase (U,Zr)C; 91.025 U (45 at.%), 5.098 C (50 at.%), 3.876 Zr (5.0 at.%); treatment at 2273 K for 35 hr; crystalline parameter 4.935 ± 0.002 Å.
2*	702	Bocker, S. and Boncher, R.	1969	L	293-1273	Composition No. 12	Phase (U,Zr)C; 91.55 U (47 at.%), 4.717 C (48 at.%), 3.732 Zr (5.0 at.%); treatment at 2173 K for 110 hr; crystalline parameter 4.9348 ± 0.0005 Å.
3*	703	Adam, J., Harrison, J.W., Riviere, J.C., and Thorpe, T.	1963		298-1373	$(U_{0.46}Zr_{0.54})C$	67.4 UC, 32.6 ZrC; two stage sintered rod; linear expansion coefficient determined by comparing with a standard in a Chevenard apparatus.
4	704	Kempter, C.P. and Merryman, R.G.	1965	X	310-1273	$(U_{0.7}Zr_{0.3})C_{0.97}$	Fabricated from cylinder of normal composition $(U_{0.3},Zr_{0.7})C$; 0.635 cm cylinder formed by hot pressing a mixture of UH_3, ZrH_2, and graphite, final vacuum pressing carried out at 4000 psi, and 2173 K for 40 min; measured density 8.78 g per cm^3, x-ray exposures made with nickel radiation, using gold as internal standard, data calculated from lattice parameters; lattice parameter reported at 298 K as 4.7821 Å with standard deviation ranging from 6×10^{-5} to 14×10^{-5} Å.
5*	705	Bocker, S.	1969	L	293-1273		$(U_{0.9}Zr_{0.1})C$; specimen cast in arc furnace.
6*	705	Bocker, S.	1969	L	293-1273		$(U_{0.9}Zr_{0.1})C_{0.92}$; similar to the above specimen.
7	442	Bowman, A.L., Krikorian, N.H., and Neveson, N.G.	1972	X	293-2523		89.54 ZrC, 10.46 UC, 0.0140 N, 0.0905 O; UO_2 + ZrO_2 powder mixed with Varcum binder and Dylon carbon black to give $(U_x Zr_{1-x})C$ plus a mole of excess carbon, then cured for 63 hr to 523 K; baked from 623 to 1023 K in 63 hr and fried to 2423 K for 2 hr; crushed and then heated to 323 K below solidus for 2 hr and cooled under flowing argon; powdered specimen placed in parallel-sided neutron diffraction graphite holders, heated to 2473 K for 4-6 hr in vacuum (~5×10^{-6} torr) prior to measurement; expansion measured with high-temperature neutron diffraction; lattice parameter reported at 293 K as 4.7276 Å.
8	442	Bowman, A.L., et al.	1972	X	293-2521		78.61 ZrC, 21.39 UC, 0.0120 N, 0.0885 O; similar to the above specimen; lattice parameter reported at 293 K as 4.7102 Å.
9	442	Bowman, A.L., et al.	1972	X	293-2541		67.31 ZrC, 32.69 UC, 0.0120 N, 0.0710 O; similar to the above specimen; lattice parameter reported at 293 K as 4.7472 Å.
10	442	Bowman, A.L., et al.	1972	X	293-2518		65.13 ZrC, 34.87 UC, 0.0120 N, 0.0785 O; similar to the above specimen; lattice parameter reported at 293 K as 4.7510 Å.

* Not shown in figure.

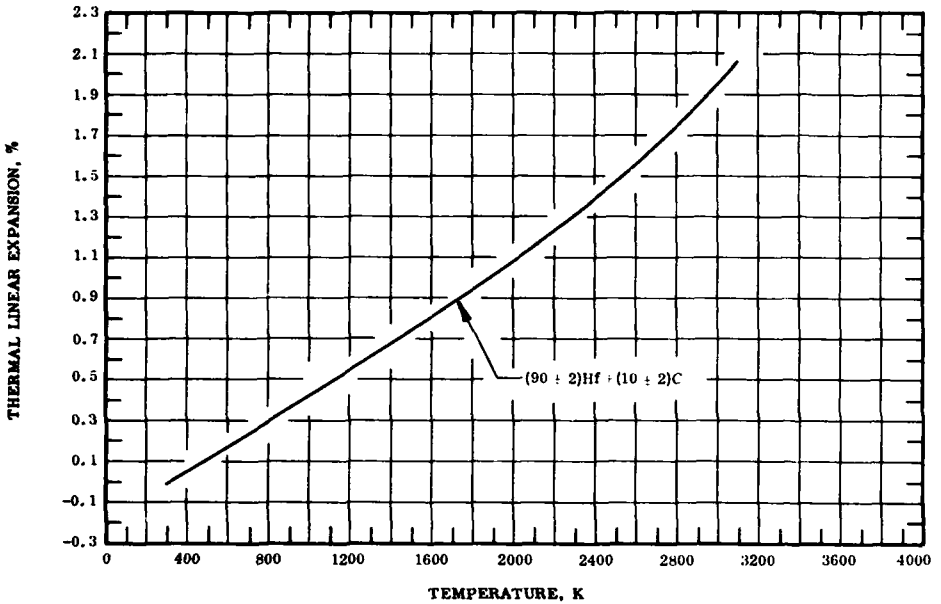
DATA TABLE 264. THERMAL LINEAR EXPANSION OF URANIUM MONOCARBIDE + ZIRCONIUM CARBIDE UC + ZrC

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.0000
873	0.5945
1273	1.0427
CURVE 2*	
293	0.000
873	0.577
1273	1.0466
CURVE 3*	
298	0.003
373	0.044
673	0.323
773	0.408
873	0.505
1373	0.940
CURVE 4	
310	0.000
538	0.158
649	0.238
788	0.339
910	0.439
1080	0.580
1164	0.656
1273	0.759
CURVE 5*	
293	0.000
873	0.595
1273	1.043
CURVE 6*	
293	0.000
873	0.577
1273	1.048
CURVE 7	
293	0.000*
299	0.002*
1145	0.619
1276	0.706
1361	0.789
1459	0.865
1544	0.935
1605	0.992
1705	1.062
1822	1.168
1886	1.216
1924	1.275
1959	1.297
1988	1.309
2085	1.400
2182	1.487
2267	1.572
2367	1.637
2376	1.684
2435	1.703
2523	1.798
CURVE 8	
293	0.000*
1176	0.641
1273	0.715*
1359	0.777
1428	0.845
1521	0.917
1623	0.998
1737	1.100
1838	1.193
1930	1.289
2008	1.361
2089	1.440
2195	1.520
2303	1.628
2370	1.705
2471	1.824
2521	1.849
CURVE 9	
293	0.000*
303	0.004*
1127	0.588
1224	0.676
1305	0.752
1386	0.824
1469	0.895
1528	0.958
1622	1.030
1672	1.074
1727	1.116
1777	1.184
1876	1.260
1965	1.350
2061	1.472
2143	1.542
2210	1.595
2294	1.677
2365	1.734
2423	1.784
2503	1.852
2541	1.885
CURVE 10	
293	0.000*
302	0.008*
1161	0.627
1223	0.667
1294	0.737
1377	0.810
1461	0.859*
1565	0.968
1606	1.101
1828	1.204
1921	1.288
2021	1.377
2114	1.467
2221	1.562
2299	1.629
2355	1.680
2382	1.694
2445	1.766
2518	1.840

* Not shown in figure.

FIGURE AND TABLE NO. 265R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF HAFNIUM CARBIDE + CARBON HfC + C



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	6.15
350	0.035	6.15
400	0.066	6.16
500	0.128	6.18
600	0.190	6.19
700	0.252	6.22
800	0.313	6.24
900	0.375	6.27
1000	0.437	6.30
1200	0.562	6.39
1400	0.690	6.53
1600	0.822	6.75
1800	0.959	7.02
2000	1.103	7.38
2200	1.255	7.77
2400	1.415	8.25
2600	1.585	8.80
2800	1.767	9.40
3000	1.961	10.05
3100	2.063	10.38

REMARKS

The recommended values are based on the data for (90 ± 2) HfC + (10 ± 2) C with a density of about 9.1 g cm^{-3}. These values are considered accurate to within ±5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.189 + 6.543 \times 10^{-4} T - 5.423 \times 10^{-8} T^2 + 2.498 \times 10^{-11} T$$

The tabulated values for the coefficient of thermal expansion are calculated primarily by differentiating the above equation and are considered accurate to about ±7%.

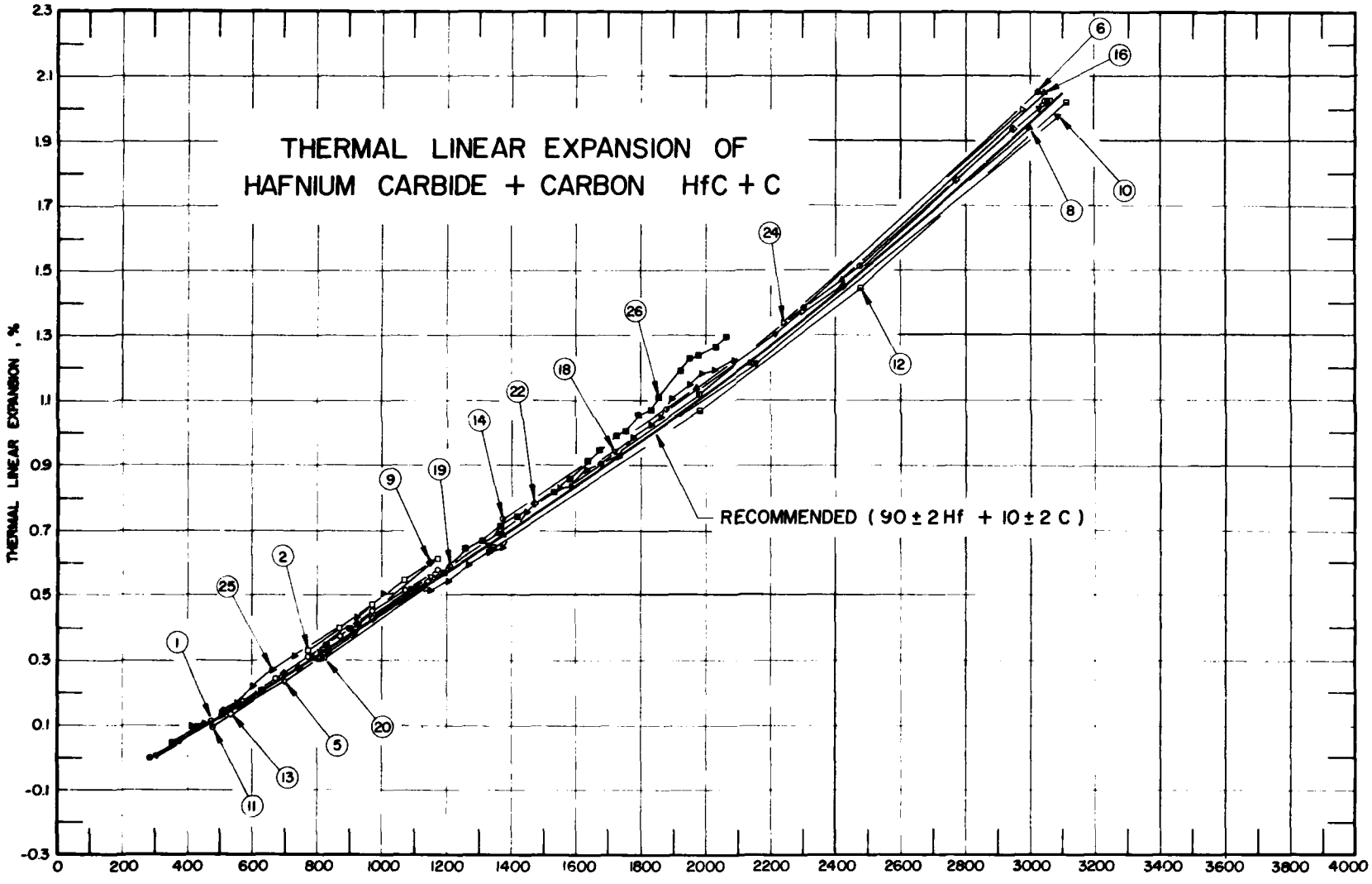

THERMAL LINEAR EXPANSION OF
HAFNIUM CARBIDE + CARBON HfC + C
RECOMMENDED (90 ± 2 Hf + 10 ± 2 C)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
0.3
0.1
-0.1
-0.3
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000

FIGURE 265

SPECIFICATION TABLE 265. THERMAL LINEAR EXPANSION OF HAFNIUM CARBIDE + CARBON HfC + C

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	706	Adams, R.P., Copeland, M.L., Deardorff, D.K., and Lincoln, R.L.	1968	L	373-1173		94.9 HfC and 5.1 C.
2	706	Adams, R.P., et al.	1968	L	373-1173		92.3 HfC and 7.7 C.
3*	706	Adams, R.P., et al.	1968	L	373-1173		89.6 HfC and 10.4 C.
4*	706	Adams, R.P., et al.	1968	L	373-1173		87.7 HfC and 12.3 C.
5	692	Foster, E.L. and Nelson, S.G.	1968	L	302-1150	1596A-1	92.2 HfC and 7.8 C; specimen machined from castings prepared by arc-melting and drop casting process; expansion measured in helium or argon atmosphere; density 9.19 g cm^3; zero-point correction is 0.005%.
6	692	Foster, E.L. and Nelson, S.G.	1968	L	283-3028	1596A-1	Same as the above specimen except it is the second measurement and zero-point correction is -0.006%.
7*	692	Foster, E.L. and Nelson, S.G.	1968	L	303-919	1596A-2	Similar to the above specimen except density reported at 9.11 g cm^3 and zero-point correction is 0.005%.
8	692	Foster, E.L. and Nelson, S.G.	1968	L	293-3000	1596A-2	Same as the above specimen except second measurement.
9	692	Foster, E.L. and Nelson, S.G.	1968	L	303-1148	1596B	Similar to the above specimen except density is 9.09 g cm^3 and zero-point correction is 0.006%.
10	692	Foster, E.L. and Nelson, S.G.	1968	L	829-3089	1596B	Same as the above specimen except second measurement.
11	692	Foster, E.L. and Nelson, S.G.	1968	L	303-1144	1650A-1	91.7 HfC and 8.3 C; similar to the above specimen except density 9.07 g cm^3 and zero-point correction is 0.005%.
12	692	Foster, E.L. and Nelson, S.G.	1968	L	285-3117	1650A-1	Same as the above specimen except second measurement and zero-point correction is -0.005%.
13	692	Foster, E.L. and Nelson, S.G.	1968	L	310-1143	1650A-2	Similar to the above specimen except density 8.98 g cm^3 and zero-point correction is 0.007%.
14	692	Foster, E.L. and Nelson, S.G.	1968	L	293-3047	1650A-2	Same as the above specimen except second measurement.
15*	692	Foster, E.L. and Nelson, S.G.	1968	L	293-1144	1652A-1	91.4 HfC and 8.6 C; similar to the above specimen except density 9.06 g cm^3.
16	692	Foster, E.L. and Nelson, S.G.	1968	L	293-3047	1652A-1	Same as the above specimen except second measurement.
17*	692	Foster, E.L. and Nelson, S.G.	1968	L	293-1141	1652A-2	Similar to the above specimen except density 8.96 g cm^3.
18	692	Foster, E.L. and Nelson, S.G.	1968	L	284-3033	1652A-2	Same as the above specimen except second measurement and zero-point correction is -0.006%.
19	692	Foster, E.L. and Nelson, S.G.	1968	L	293-1212	1653A-1	91.3 HfC and 8.7 C; similar to the above specimen except density 9.06 g cm^3.
20	692	Foster, E.L. and Nelson, S.G.	1968	L	285-3061	1653A-1	Same as the above specimen except second measurement and zero-point correction is -0.005%.
21*	692	Foster, E.L. and Nelson, S.G.	1968	L	293-1146	1653A-2	Similar to the above specimen except density 8.93 g cm^3.
22	692	Foster, E.L. and Nelson, S.G.	1968	L	283-2950	1653A-2	Same as the above specimen except second measurement and zero-point correction is -0.006%.

* Not shown in figure.

SPECIFICATION TABLE 265. THERMAL LINEAR EXPANSION OF HAFNIUM CARBIDE + CARBON HfC + C (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
23*	692	Foster, E. L. and Nelson, S. G.	1968	L	293-1139	1656	90.6 HfC and 9.4 C; similar to the above specimen except density 8.95 g cm^3.
24	692	Foster, E. L. and Nelson, S. G.	1968	L	293-2978	1655A	Similar to the above specimens.
25	693	Poole, H. G.	1966	T	373-2083	HfC 412	89.7 HfC and 10.3 C; specimen dimensions 0.635 x 1.27 x 7.61 cm, heated in vacuum.
26	693	Poole, H. G.	1966	T	353-2063	HfC 419	88.0 HfC and 12.0 C; similar to the above specimen.

* Not shown in figure.

DATA TABLE 265. THERMAL LINEAR EXPANSION OF HAFNIUM CARBIDE + CARBON HfC + C

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
373	0.051
473	0.114
573	0.179
673	0.244
773	0.313
873	0.382
973	0.456
1073	0.519
1173	0.581

CURVE 2

T	$\Delta L/L_0$
373	0.052*
473	0.117*
573	0.185*
673	0.257*
773	0.330
873	0.403
973	0.477
1073	0.550
1173	0.619

CURVE 3*

T	$\Delta L/L_0$
373	0.051
473	0.115
573	0.181
673	0.250
773	0.322
877	0.394
973	0.468
1073	0.540
1173	0.610

CURVE 4*

T	$\Delta L/L_0$
373	0.051
473	0.116
573	0.180
673	0.247
773	0.315
873	0.389
973	0.459
1073	0.532
1173	0.601

CURVE 5

T	$\Delta L/L_0$
302	0.005
478	0.101*
700	0.237
920	0.385
1150	0.557

CURVE 6

T	$\Delta L/L_0$
283	-0.006
837	0.324
1675	0.905
2305	1.387
3028	2.058

CURVE 7*

T	$\Delta L/L_0$
303	0.005
478	0.101
696	0.243
919	0.396

CURVE 8

T	$\Delta L/L_0$
293	0.000*
840	0.329*
1376	0.687
2139	1.215
3000	1.946

CURVE 9

T	$\Delta L/L_0$
303	0.006
510	0.142
700	0.259
924	0.412
1148	0.600

CURVE 10

T	$\Delta L/L_0$
829	0.321*
1330	0.654
2155	1.213
3089	1.979

CURVE 11

T	$\Delta L/L_0$
303	0.005*
479	0.093
702	0.238*
914	0.379
1144	0.557*

CURVE 12

T	$\Delta L/L_0$
285	-0.005*
808	0.305
1344	0.647
1983	1.071
2478	1.452
3117	2.026

CURVE 13

T	$\Delta L/L_0$
310	0.007*
537	0.135
810	0.316*
975	0.429
1143	0.542

CURVE 14

T	$\Delta L/L_0$
293	0.000*
769	0.308*
1369	0.738
1880	1.074
2478	1.519
3047	2.028

CURVE 15*

T	$\Delta L/L_0$
293	0.000
532	0.130
811	0.313
983	0.434
1144	0.540

CURVE 16

T	$\Delta L/L_0$
293	0.000*
789	0.307
1355	0.693
1969	1.140

CURVE 16 (cont.)

T	$\Delta L/L_0$
2422	1.473
3047	2.059

CURVE 17*

T	$\Delta L/L_0$
293	0.000
478	0.089
699	0.234
919	0.389
1141	0.547

CURVE 18

T	$\Delta L/L_0$
284	-0.006*
811	0.326
1097	0.520
1719	0.942
2217	1.304
3033	2.000

CURVE 19

T	$\Delta L/L_0$
293	0.000*
533	0.129*
812	0.314*
1057	0.481
1148	0.544*
1212	0.586

CURVE 20

T	$\Delta L/L_0$
285	-0.005*
824	0.312
1341	0.653
1980	1.120
2422	1.462*
3061	2.032

CURVE 21*

T	$\Delta L/L_0$
295	0.000
533	0.125
812	0.307
978	0.423
1146	0.541

CURVE 22

T	$\Delta L/L_0$
283	-0.006
744	0.275
1470	0.782
1878	1.047
2422	1.454
2769	1.782
2950	1.941

CURVE 23*

T	$\Delta L/L_0$
293	0.000
477	0.097
699	0.244
919	0.395
1139	0.551

CURVE 24

T	$\Delta L/L_0$
293	0.000*
1162	0.562*
1714	0.948*
2244	1.339
2978	2.006

CURVE 25

T	$\Delta L/L_0$
373	0.060*
413	0.099
448	0.104
503	0.126
548	0.169
603	0.272
663	0.269
733	0.317
773	0.327*
858	0.375*
923	0.428
1003	0.503
1148	0.513
1208	0.541
1263	0.593
1328	0.633
1373	0.645
1443	0.757
1473	0.791*
1543	0.832
1583	0.836
1633	0.885
1683	0.923*

CURVE 25 (cont.)

T	$\Delta L/L_0$
1733	0.933
1773	0.984
1823	1.023
1858	1.050
1893	1.107
1933	1.148
1983	1.180
2023	1.190
2083	1.224

CURVE 26

T	$\Delta L/L_0$
353	0.047
363	0.055*
433	0.097
473	0.116*
513	0.150*
568	0.183*
633	0.207
703	0.261*
768	0.304*
828	0.347
903	0.399
983	0.451*
1063	0.473*
1133	0.546*
1193	0.570
1258	0.643
1313	0.665
1363	0.715
1418	0.743
1483	0.786*
1533	0.819
1583	0.860
1638	0.916
1673	0.952
1723	0.992
1753	1.007
1793	1.057
1833	1.068
1858	1.109
1923	1.190
1948	1.230
1978	1.239
2033	1.263
2063	1.296

* Not shown in figure.

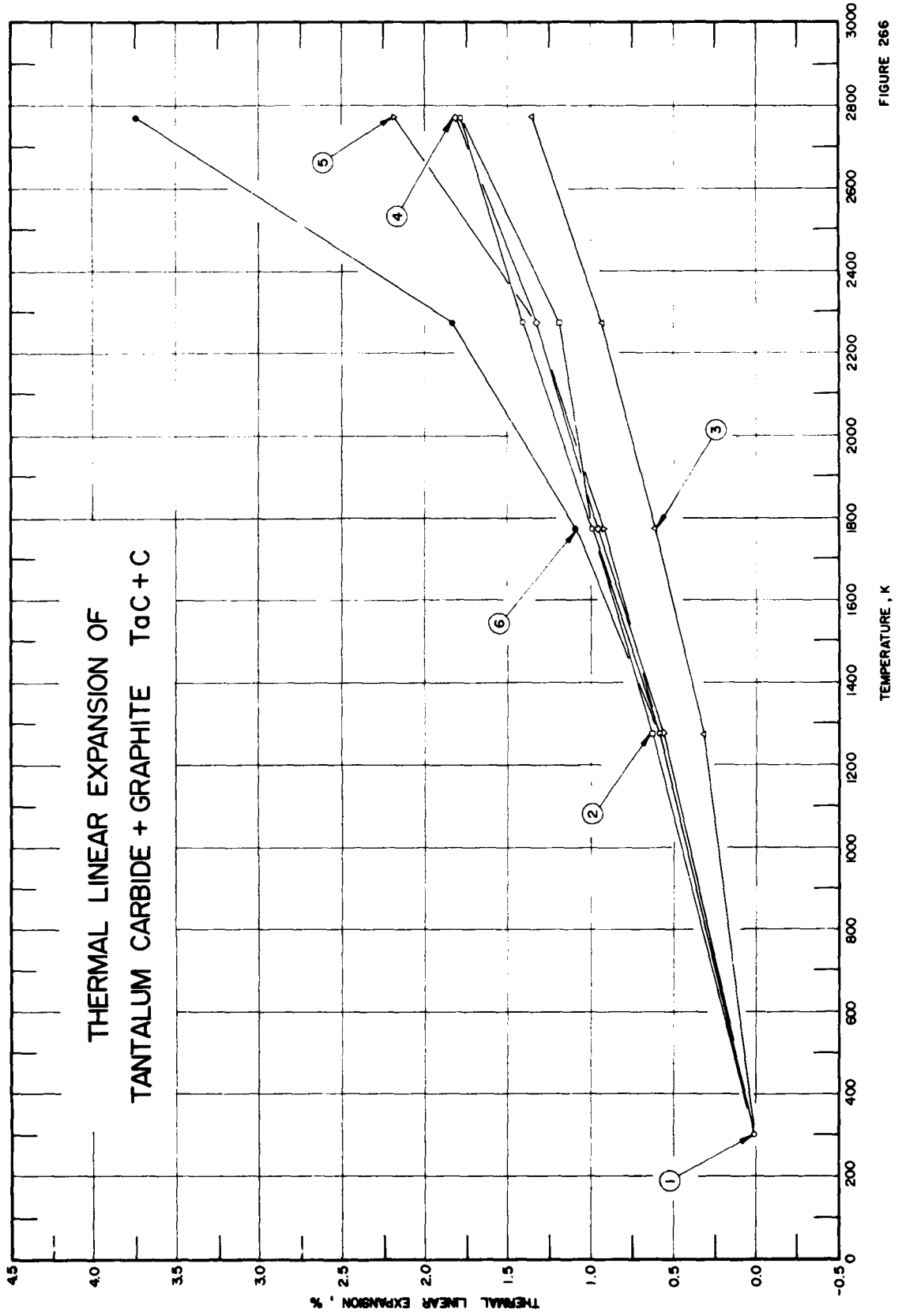

THERMAL LINEAR EXPANSION OF
TANTALUM CARBIDE + GRAPHITE TaC + C
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
1
2
3
4
5
6

FIGURE 266

SPECIFICATION TABLE 266. THERMAL LINEAR EXPANSION OF TANTALUM CARBIDE + GRAPHITE TaC + C

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	432	Miccioli, B.R. and Julien, H.P.	1965	T	300-2773		90 volume % TaC; hot pressed specimen; density 11.70 g cm^{-3}; expansion measured perpendicular to pressing.
2	432	Miccioli, B.R. and Julien, H.P.	1965	T	300-2773		60 volume % TaC; similar to the above specimen except density 8.67 g cm^{-3}.
3	432	Miccioli, B.R. and Julien, H.P.	1965	T	300-2773		10 volume % TaC; similar to the above specimen except density 2.88 g cm^{-3}.
4	432	Miccioli, B.R. and Julien, H.P.	1965	T	300-2773		90 volume % TaC; similar to the above specimen except density 12.00 g cm^{-3}; expansion parallel to pressing.
5	432	Miccioli, B.R. and Julien, H.P.	1965	T	300-2773		50 volume % TaC; similar to the above specimen except density 8.31 g cm^{-3}.
6	432	Miccioli, B.R. and Julien, H.P.	1965	T	300-2773		10 volume % TaC; similar to the above specimen except density 3.18 g cm^{-3}.

DATA TABLE 266. THERMAL LINEAR EXPANSION OF TANTALUM CARBIDE + GRAPHITE TaC + C

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 3		CURVE 5	
300	0.004	300	0.002*	300	0.004*
1273	0.588	1273	0.316	1273	0.596*
1773	0.996	1773	0.614	1773	0.921
2273	1.408	2273	0.936	2273	1.327*
2773	1.786	2773	1.357	2773	2.185
CURVE 2		CURVE 4		CURVE 6	
300	0.004*	300	0.004*	300	0.004*
1273	0.626	1273	0.570	1273	0.591*
1773	0.981*	1773	0.952	1773	1.088
2273	1.194	2273	1.327	2273	1.833
2773	1.793*	2773	1.818	2773	3.745

* Not shown in figure.

SPECIFICATION TABLE 267. THERMAL LINEAR EXPANSION OF TITANIUM CARBIDE + CARBON TiC + C

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	693	Poole, H. G.	1966	T	393-1978	TiC 461 (run X-10)	77.9 TiC and 22.1 C; rectangular specimen, 0.635 x 1.27 x 7.61 cm; heated in vacuum.
2*	693	Poole, H. G.	1966	T	333-1908	TiC 467B (run X-11)	81.5 TiC and 18.5 C; rectangular specimen, 0.635 x 1.27 x 7.61 cm; heated in vacuum.

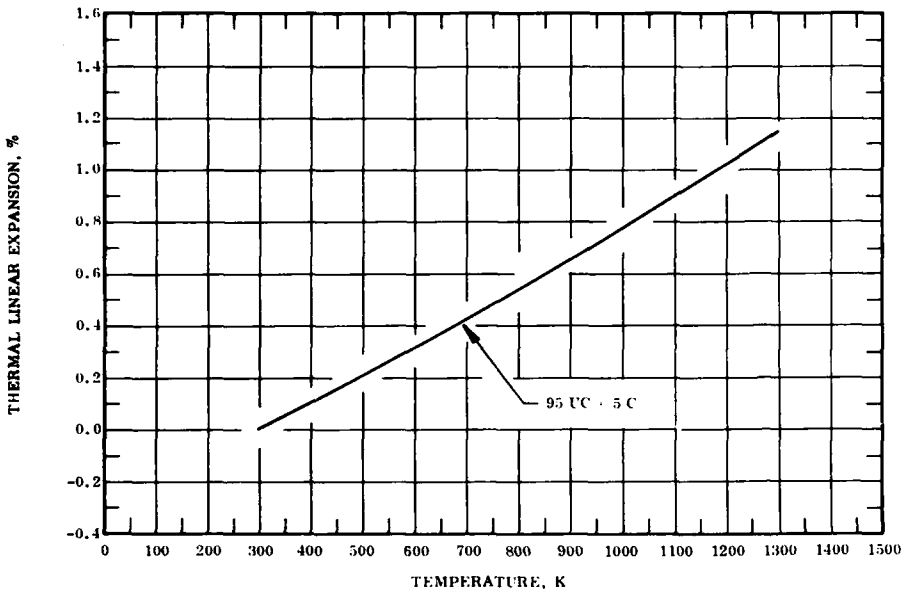
DATA TABLE 267. THERMAL LINEAR EXPANSION OF TITANIUM CARBIDE + CARBON TiC + C

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*	
393	0.008	333	0.037
483	0.140	408	0.152
603	0.235	511	0.235
727	0.315	618	0.322
918	0.448	759	0.443
1013	0.542	893	0.546
1151	0.655	1057	0.658
1268	0.740	1180	0.763
1395	0.863	1271	0.848
1488	0.943	1393	0.941
1593	1.047	1483	1.046
1683	1.118	1583	1.114
1763	1.180	1673	1.229
1853	1.285	1733	1.289
1888	1.405	1808	1.438
1978	1.453	1878	1.508
		1903	1.511
		1908	1.536

* No figure given.

FIGURE AND TABLE NO. 268R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF URANIUM MONOCARBIDE + CARBON UC + C



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	9.3
300	0.005	9.3
400	0.105	10.2
500	0.209	10.6
600	0.317	11.0
700	0.429	11.4
800	0.544	11.7
900	0.661	11.9
1000	0.781	12.0
1100	0.902	12.1
1200	1.024	12.2
1300	1.146	12.3

REMARKS

The recommended values are based on the data for 95 UC + 5 C samples. These values are considered accurate to within ± 5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.258 + 7.816 \times 10^{-4}\ T + 3.510 \times 10^{-7}\ T^2 - 9.326 \times 10^{-11}\ T^3$$

The tabulated values for the coefficient of thermal expansion are calculated primarily by differentiating the above equation and are considered accurate to about ± 7%.

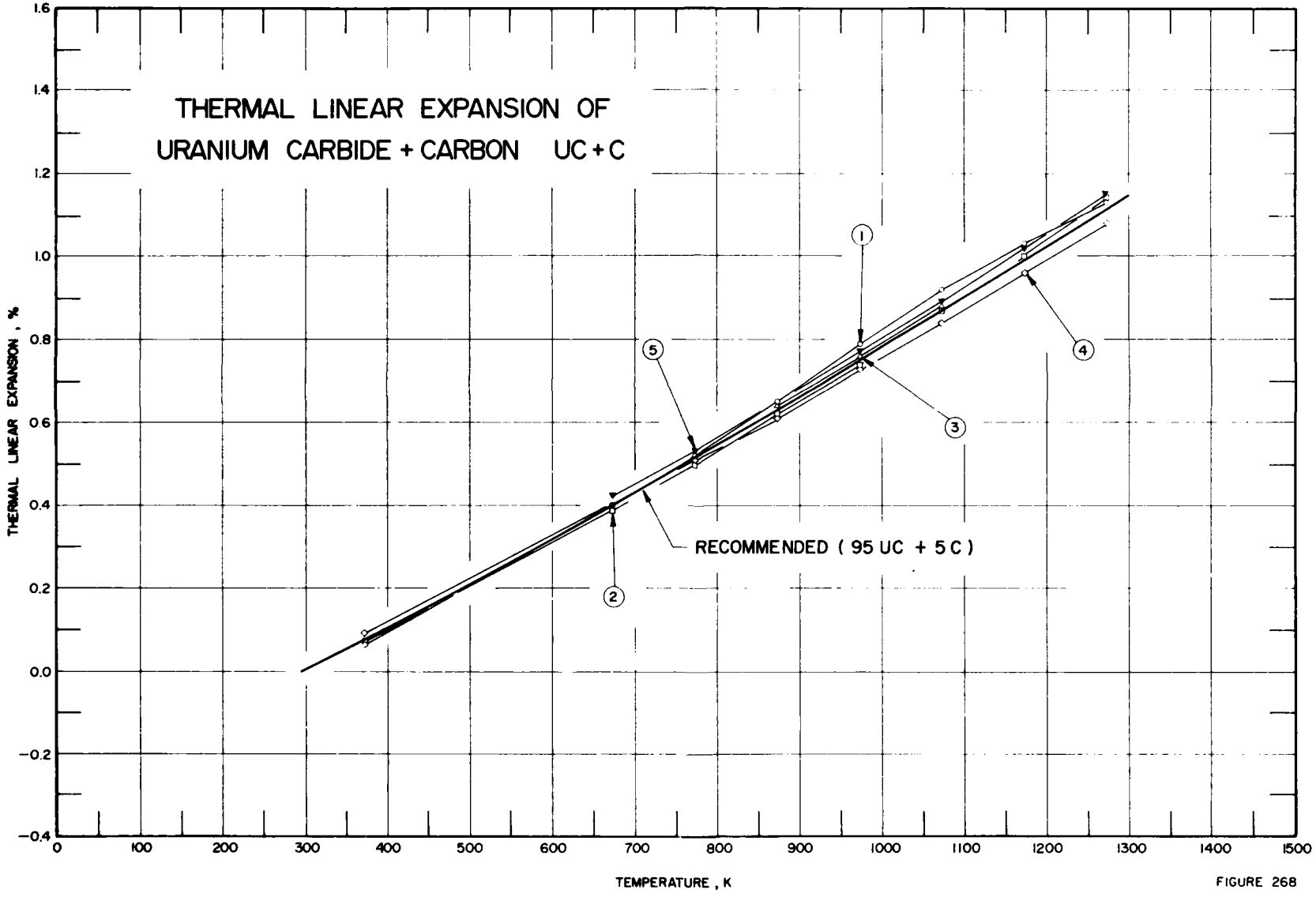

THERMAL LINEAR EXPANSION OF
URANIUM CARBIDE + CARBON UC + C
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED (95 UC + 5 C)
1
2
3
4
5
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 268

SPECIFICATION TABLE 268. THERMAL LINEAR EXPANSION OF URANIUM MONOCARBIDE + CARBON UC + C

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	697	Gordon, E. and Crane, J.	1963	L	373-1273		95.6 UC and 4.4 C; cast specimen 2.49 cm long and 0.800 cm diameter; expansion measured in vacuum of 10^{-4} mm Hg with heating rate of 1.5 K/minute.
2	697	Gordon, E. and Crane, J.	1963	L	373-1273		Similar to the above specimen except sintered.
3	697	Gordon, E. and Crane, J.	1963	L	373-1273		95.2 UC and 4.8 C; similar to the above specimen except cast.
4	697	Gordon, E. and Crane, J.	1963	L	373-1273		Similar to the above specimen except sintered.
5	697	Gordon, E. and Crane, J.	1963	L	373-1273		94.8 UC and 5.2 C; similar to the above specimen except cast.

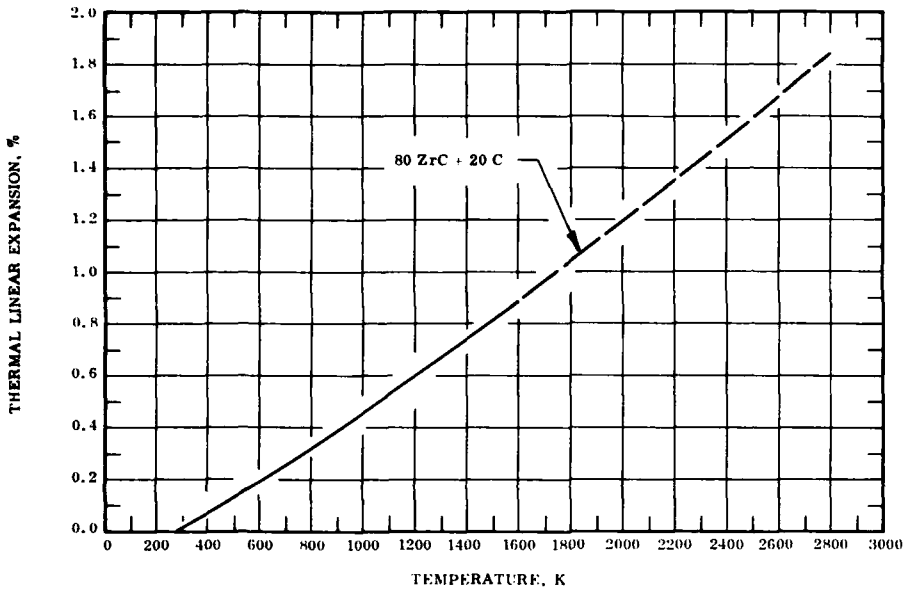
DATA TABLE 268. THERMAL LINEAR EXPANSION OF URANIUM MONOCARBIDE + CARBON UC + C

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 3		CURVE 5	
373	0.065	373	0.070*	373	0.075*
673	0.400	673	0.400*	673	0.420
773	0.520	773	0.520*	773	0.530
873	0.650	873	0.640	873	0.650*
973	0.790	973	0.760	973	0.770
1073	0.920	1073	0.880	1073	0.890
1173	1.030	1173	1.000*	1173	1.020
1273	1.130	1273	1.130*	1273	1.150
CURVE 2		CURVE 4			
373	0.072	373	0.094		
673	0.390	673	0.400*		
773	0.500	773	0.510		
873	0.620	873	0.610		
973	0.740	973	0.730		
1073	0.870	1073	0.840		
1173	1.000	1173	0.960		
1273	1.140	1273	1.080		

* Not shown in figure.

FIGURE AND TABLE NO. 269R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE + CARBON ZrC + C



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	5.9
300	0.005	5.9
400	0.064	6.0
500	0.125	6.2
600	0.187	6.3
700	0.251	6.4
800	0.316	6.6
900	0.383	6.7
1000	0.450	6.8
1200	0.590	7.1
1400	0.733	7.3
1600	0.882	7.5
1800	1.034†	7.7
2000	1.190†	7.9
2200	1.349†	8.1
2400	1.512†	8.2
2600	1.677†	8.3
2800	1.845†	8.4

† Provisional values.

REMARKS

The recommended values are based on the data for 80 ZrC + 20 C with a density of about 5.6 g cm^{-3}. These values are considered accurate to about ± 5% at temperatures below 1600 K and ± 10% above 1600 K and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.164 + 5.378 \times 10^{-4}\, T + 8.302 \times 10^{-8}\, T^2 - 6.760 \times 10^{-12}\, T^3$$

The tabulated values for the coefficient of thermal expansion are derived primarily by differentiating the above equation and are considered accurate to about ± 10%.

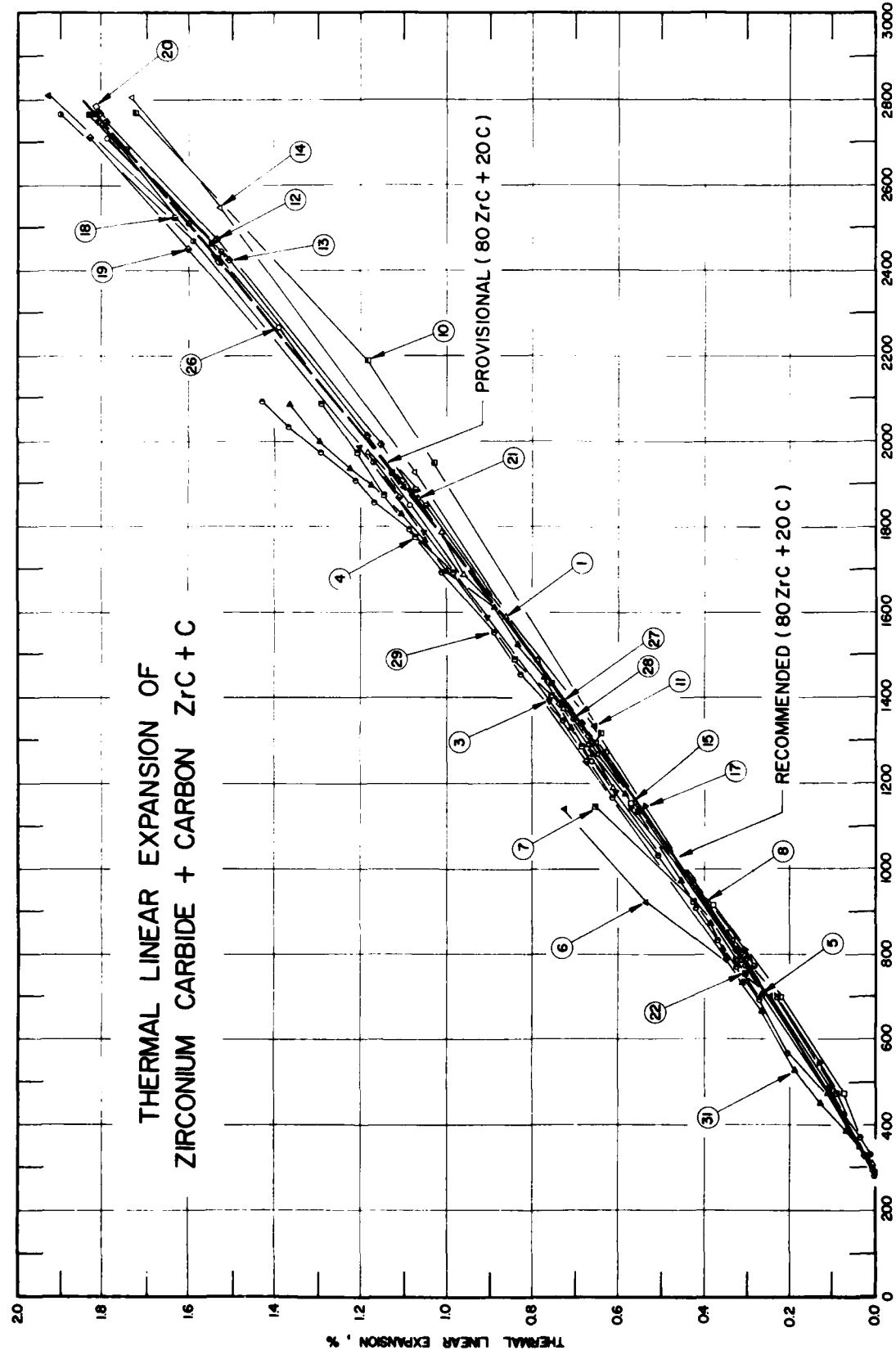

THERMAL LINEAR EXPANSION OF
ZIRCONIUM CARBIDE + CARBON ZrC + C
PROVISIONAL (80 ZrC + 20 C)
RECOMMENDED (80 ZrC + 20 C)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000

FIGURE 269

SPECIFICATION TABLE 269. THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE + CARBON ZrC + C

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	691	Aronson, S., Cisney, E., and Auskern, A. B.	1966	X	301-1972		69.79 ZrC and 34.21 C; prepared by reacting zirconium hydride and carbon in vacuum at 1773 K to 2273 K; lattice parameter reported at 301 K as 4.6885 Å; 4.6882 Å at 293 K determined by graphical extrapolation.
2*	691	Aronson, S., et al.	1966	X	299-2075		58.09 ZrC and 41.91 C; similar to the above; lattice parameter reported at 299 K as 4.700 Å; 4.699 Å at 293 K determined by graphical extrapolation.
3	691	Aronson, S., et al.	1966	X	301-1987		62.87 ZrC and 37.13 C; similar to the above; lattice parameter reported at 301 K as 4.6963 Å; 4.6960 Å at 293 K determined by graphical extrapolation.
4	691	Aronson, S., et al.	1966	X	298-2085		59.25 ZrC and 40.75 C; similar to the above; lattice parameter reported at 298 K as 4.7026 Å; 4.7024 Å at 293 K determined by graphical extrapolation.
5	692	Foster, E. L. and Nelson, S. G.	1968	L	296-703	1428A	20.5 C; specimen machined from castings prepared by arc melting and drop casting process; initial length 7.619 cm; final length 8.041 cm; weight of sample 52.588 gm; density reported as 5.42 g cm^3; expansion made in air inside quartz dilatometer; authors reported that specimen disintegrated after heating.
6	692	Foster, E. L. and Nelson, S. G.	1968	L	296-1140	1429A	19.5 C; similar to the above; initial length 5.077 cm; final length 5.077 cm; weight of sample 35.384 gm; reported density 5.41 g cm^3; expansion made in air; and inside quartz dilatometer.
7	692	Foster, E. L. and Nelson, S. G.	1968	L	299-1149	1429B	19.6 C; similar to the above; initial length 7.619 cm; final length 7.628 cm; weight of sample 54.118 gm; reported density 5.58 g cm^{-3}; expansion made in air; and inside quartz dilatometer.
8	692	Foster, E. L. and Nelson, S. G.	1968	L	298-1141	1429E	19.6 C; similar to the above; initial length 7.617 cm; final length 7.621 cm; weight of sample 54.2045 gm; reported density 5.58 g cm^{-3}; expansion made in air; and inside quartz dilatometer.
9*	692	Foster, E. L. and Nelson, S. G.	1968	L	298-1141	1439A	20.1 C; similar to the above; initial length 7.613 cm; final length 7.617 cm; weight of sample 53.451 gm; reported density 5.51 g cm^{-3}; expansion measured inside quartz dilatometer in argon atmosphere.
10	692	Foster, E. L. and Nelson, S. G.	1968	L	298-2769	1428A	20.5 C; same as curve 5; initial length 5.033 cm; final length 4.968 cm; weight of sample 34.693 gm; reported density 5.42 g cm^{-3}; specimen made by mating pieces of curve 5; expansion measured in graphite dilatometer in argon atm.
11	692	Foster, E. L. and Nelson, S. G.	1968	L	297-2811	1429A	19.5 C; same as curve 6; expansion measured in graphite dilatometer in argon atmosphere; initial length 5.072 cm; final length 5.071 cm; weight of sample 34.9405 gm; reported density 5.41 g cm^{-3}.
12	692	Foster, E. L. and Nelson, S. G.	1968	L	294-2755	1429B	19.6 C; same as curve 7; expansion measured in graphite dilatometer in argon atmosphere; initial length 7.624 cm; final length 7.616 cm; weight of sample 53.6250 gm; reported density 5.58 g cm^{-3}.
13	692	Foster, E. L. and Nelson, S. G.	1968	L	283-2769	1429E	19.6 C; same as curve 8; expansion measured in graphite dilatometer in argon atmospher; initial length 7.616 cm; final length 7.609 cm; weight of sample 53.9184 gm; reported density 5.58 g cm^{-3}.
14	692	Foster, E. L. and Nelson, S. G.	1968	L	294-2805	1439A	20.1 C; same as curve 9; expansion measured in graphite dilatometer in argon atmosphere; initial length 7.615 cm; final length 7.606 cm; weight of sample 53.4040 gm; reported density 5.51 g cm^{-3}.

* Not shown in figure.

SPECIFICATION TABLE 269. THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE + CARBON ZrC + C (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
15	692	Foster, E. L. and Nelson, S. G.	1968	L	304-1153	1543A	23.7 C; similar to the above; initial length 7.587 cm; final length 7.588 cm; weight of sample 51.3191 gm; reported density 5.31 g cm^{-3}; expansion measured in quartz dilatometer in argon atmosphere.
16	692	Foster, E. L. and Nelson, S. G.	1968	L	303-1143	1546A	25.9 C; similar to the above; initial length 7.6274 cm; final length 7.6286 cm; weight of sample 51.7252 gm; reported density 5.31 g cm^{-3}; expansion measured in quartz dilatometer in argon atmosphere.
17	692	Foster, E. L. and Nelson, S. G.	1968	L	298-1147	1636A	22.3 C; similar to the above; initial length 7.6238 cm; final length 7.6238 cm; weight of sample 51.0343 gm; reported density 5.27 g cm^{-3}; expansion measured in quartz dilatometer in argon atmosphere.
18	692	Foster, E. L. and Nelson, S. G.	1968	L	294-2769	1391A	21.9 C; similar to the above; initial length 7.6223 cm; final length 7.6162 cm; weight of sample 51.4340 gm; reported density 5.59 g cm^{-3}; expansion measured in graphite dilatometer in argon atmosphere.
19	692	Foster, E. L. and Nelson, S. G.	1968	L	324-2717	1391B	22.5 C; similar to the above; initial length 7.6213 cm; final length 7.6195 cm; weight of sample 51.0128 gm; reported density 5.28 g cm^{-3}; expansion measured in graphite dilatometer in argon atmosphere.
20	692	Foster, E. L. and Nelson, S. G.	1968	L	292-2783	1543A	23.7 C; similar to the above; initial length 7.5931 cm; final length 7.5895 cm; weight of sample 51.2914 gm; reported density 5.31 g cm^{-3}; expansion measured in graphite dilatometer in argon atmosphere.
21	692	Foster, E. L. and Nelson, S. G.	1968	L	294-2755	1546A	25.9 C; similar to the above; initial length 7.6294 cm; final length 7.6243 cm; weight of sample 51.6898 gm; reported density 5.31 g cm^{-3}; expansion measured in graphite dilatometer in argon atmosphere.
22	692	Foster, E. L. and Nelson, S. G.	1968	L	287-2769	1636A	22.3 C; similar to the above; initial length 7.6238 cm; final length 7.6175 cm; weight of sample 51.0705 gm; reported density 5.27 g cm^{-3}; expansion measured in graphite dilatometer in argon atmosphere.
23*	692	Foster, E. L. and Nelson, S. G.	1968	L	302-1147	1556A	22.5 C; similar to the above; initial length 7.8130 cm; final length 7.8141 cm; weight of sample 52.9512 gm; reported density 5.35 g cm^{-3}; expansion measured in quartz dilatometer in argon atmosphere.
24*	692	Foster, E. L. and Nelson, S. G.	1968	L	304-922	1723A	22.6 C; similar to the above; initial length 7.6215 cm; final length 7.6218 cm; weight of sample 51.6240 gm; reported density 5.34 g cm^{-3}; expansion measured in quartz dilatometer in argon atmosphere.
25*	692	Foster, E. L. and Nelson, S. G.	1968	L	304-1157	1723B	22.6 C; similar to the above; initial length 7.6220 cm; final length 7.6220 cm; weight of sample 51.5431 gm; reported density 5.32 g cm^{-3}; expansion measured in quartz dilatometer in argon atmosphere.
26	692	Foster, E. L. and Nelson, S. G.	1968	L	294-2717	1556A	22.5 C; similar to the above; initial length 7.8138 cm; final length 7.8123 cm; weight of sample 52.9383 gm; reported density 5.35 g cm^{-3}; expansion measured in graphite dilatometer in argon atmosphere.
27	692	Foster, E. L. and Nelson, S. G.	1968	L	312-2686	1723A	22.6 C; similar to the above; initial length 7.6220 cm; final length 7.6187 cm; weight of sample 51.4335 cm; reported density 5.34 g cm^{-3}; expansion measured in graphite dilatometer in argon atmosphere.

* Not shown in figure.

SPECIFICATION TABLE 269. THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE + CARBON ZrC + C (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
28	692	Foster, E. L. and Nelson, S. G.	1968	L	280-2769	1723B	22.6 C; similar to the above; initial length 7.6203 cm; final length 7.6203 cm; weight of sample 51.5380 gm; reported density 5.32 g cm^{-3}; expansion measured in graphite dilatometer in argon atmosphere.
29	693	Poole, H. G.	1966	T	333-2093	ZrC 449	82.4 ZrC and 17.6 C; rectangular specimen, 0.35 x 1.27 x 7.61 cm; heated in vacuum.
30*	693	Poole, H. G.	1966	T	343-2038	ZrC 458	80.6 ZrC and 19.4 C; rectangular specimen, 0.635 x 1.27 x 7.61 cm; heated in vacuum.
31	693	Poole, H. G.	1966	T	333-2093	ZrC 460	79.7 ZrC and 20.3 C; rectangular specimen, 0.635 x 1.27 x 7.61 cm; heated in vacuum.

* Not shown in figure.

DATA TABLE 269. THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE + CARBON ZrC + C

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
301	0.006
1190	0.614
1284	0.666
1377	0.729
1484	0.789
1589	0.860
1683	0.960
1785	1.013
1972	1.182
CURVE 2*	
299	0.004
1185	0.615
1284	0.698
1379	0.760
1484	0.823
1597	0.934
1684	0.989
1779	1.064
1888	1.155
1977	1.238
2075	1.309
CURVE 3	
301	0.006
1181	0.603
1392	0.760
1583	0.905
1791	1.058
1981	1.203
CURVE 4	
298	0.004
1283	0.681
1405	0.759
1490	0.840
1694	0.991
1775	1.076
1879	1.146
1978	1.212
2085	1.299

T	$\Delta L/L_0$
CURVE 5	
296	0.000*
479	0.112
703	0.263
CURVE 6	
296	0.000*
485	0.106
700	0.245
921	0.537
1140	0.726
CURVE 7	
299	0.000*
478	0.091
700	0.229
922	0.426
1149	0.657
CURVE 8	
298	0.000*
489	0.105*
700	0.240*
925	0.397
1141	0.572
CURVE 9*	
298	0.000
478	0.098
700	0.239
922	0.449
1141	0.734
CURVE 10	
298	0.000*
784	0.323
1298	0.652
1319	0.640
1944	1.028
2186	1.182
2769	1.726

T	$\Delta L/L_0$
CURVE 11	
297	0.000*
857	0.348
1338	0.658
1894	1.101
2433	1.533
2811	1.927*
CURVE 12	
294	0.000*
475	0.108*
1381	0.739
1378	0.739*
1997	1.158
2478	1.538
2755	1.796
CURVE 13	
283	0.000*
802	0.316
1340	0.683
2017	1.185
2422	1.511
2769	1.805
CURVE 14	
294	0.001*
833	0.337
1265	0.643
1267	0.643*
1922	1.078
2544	1.525
2805	1.734
CURVE 15	
304	0.000*
478	0.073
700	0.220
919	0.380
1153	0.571

T	$\Delta L/L_0$
CURVE 16*	
303	0.000
485	0.089
701	0.226
909	0.370
1143	0.558
CURVE 17	
298	0.000*
544	0.125
812	0.311
978	0.429
1147	0.538
CURVE 18	
294	0.000*
855	0.345*
1433	0.759
1883	1.076
2522	1.636
2769	1.811
CURVE 19	
324	0.022
789	0.346
1250	0.677
1867	1.116
2455	1.600
2717	1.831
CURVE 20	
292	0.000*
812	0.321
1311	0.668
1908	1.109
2422	1.530
2783	1.816
CURVE 21	
294	0.000*
783	0.303

T	$\Delta L/L_0$
CURVE 21 (cont.)	
1272	0.638
1861	1.068
2428	1.513*
2755	1.813
CURVE 22	
287	0.000
758	0.303
1375	0.723*
1922	1.129
2464	1.543
2769	1.826
CURVE 23*	
302	0.000
478	0.093
700	0.237
924	0.393
1147	0.563
CURVE 24*	
304	0.000
478	0.094
700	0.236
922	0.395
CURVE 25*	
304	0.000
485	0.097
702	0.238
924	0.391
1157	0.545
CURVE 26	
294	0.000*
788	0.310
1254	0.661
1850	1.086
2267	1.397
2517	1.600
2717	1.791

T	$\Delta L/L_0$
CURVE 27	
312	0.011*
775	0.288
1394	0.728
1850	1.046
2444	1.523
2686	1.744
CURVE 28	
280	0.000
778	0.306
1349	0.702
1955	1.172
2478	1.592
2769	1.900*
CURVE 29	
333	0.012
373	0.034
423	0.070
473	0.090*
568	0.201
608	0.209*
693	0.270
768	0.323
838	0.371
908	0.420
958	0.449*
1033	0.509
1108	0.556*
1163	0.617
1233	0.628*
1298	0.687*
1343	0.728
1388	0.776*
1458	0.821
1503	0.861*
1553	0.893
1598	0.944*
1633	0.998*
1693	1.015
1753	1.054*
1793	1.083
1833	1.139*
1858	1.177

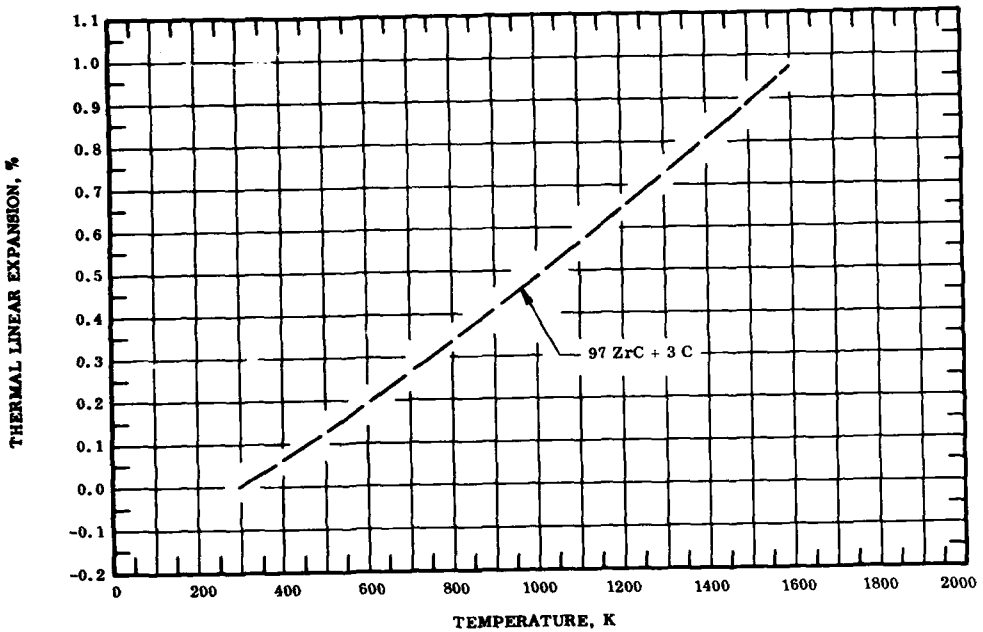
* Not shown in figure.

DATA TABLE 269. THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE + CARBON ZrC + C (continued)

T	$\Delta L/L_0$
CURVE 29 (cont.)	
1908	1.218
1953	1.247*
1978	1.299
2028	1.337*
2038	1.364
2093	1.429
CURVE 30*	
343	0.081
373	0.159
413	0.174
473	0.209
508	0.248
553	0.283
648	0.369
708	0.379
773	0.438
843	0.482
903	0.514
963	0.568
1033	0.607
1103	0.675
1173	0.723
1233	0.771
1293	0.803
1363	0.847
1398	0.882
1463	0.909
1513	0.961
1543	0.987
1583	1.020
1653	1.042
1683	1.076
1728	1.132
1773	1.155
1813	1.201
1848	1.211
1893	1.253
1933	1.293
1968	1.314
2013	1.361
2038	1.393
CURVE 31	
333	0.027*
353	0.038
383	0.064
413	0.096*
453	0.125
523	0.182
578	0.198*
663	0.263
733	0.314
808	0.356
873	0.383
963	0.452
1038	0.507*
1133	0.558
1188	0.581
1268	0.655
1328	0.710
1372	0.705*
1443	0.771
1478	0.797*
1523	0.837
1608	0.888
1633	0.935*
1693	1.005
1733	1.022*
1768	1.052
1823	1.103
1873	1.137*
1898	1.179
1938	1.215
1978	1.225*
2008	1.309
2053	1.345*
2093	1.361

* Not shown in figure.

FIGURE AND TABLE NO. 270R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE + GRAPHITE ZrC + C



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	5.4
300	0.005	5.6
400	0.061	5.9
500	0.123	6.4
600	0.189	6.8
700	0.258	7.1
800	0.331	7.4
900	0.406	7.7
1000	0.484	7.9
1100	0.563	8.0
1200	0.644	8.1
1300	0.725	8.1
1400	0.807	8.2
1500	0.888	8.2
1600	0.969	8.2

REMARKS

The provisional values are based on the data for (95 ± 2) ZrC + (5 ± 2) C samples hot-pressed at high pressure and temperature. These values are considered accurate to within ± 7% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.132 + 3.600 \times 10^{-4}\, T + 3.400 \times 10^{-7}\, T^2 - 8.456 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are calculated primarily by differentiating the above equation and are considered accurate to about ± 10%.

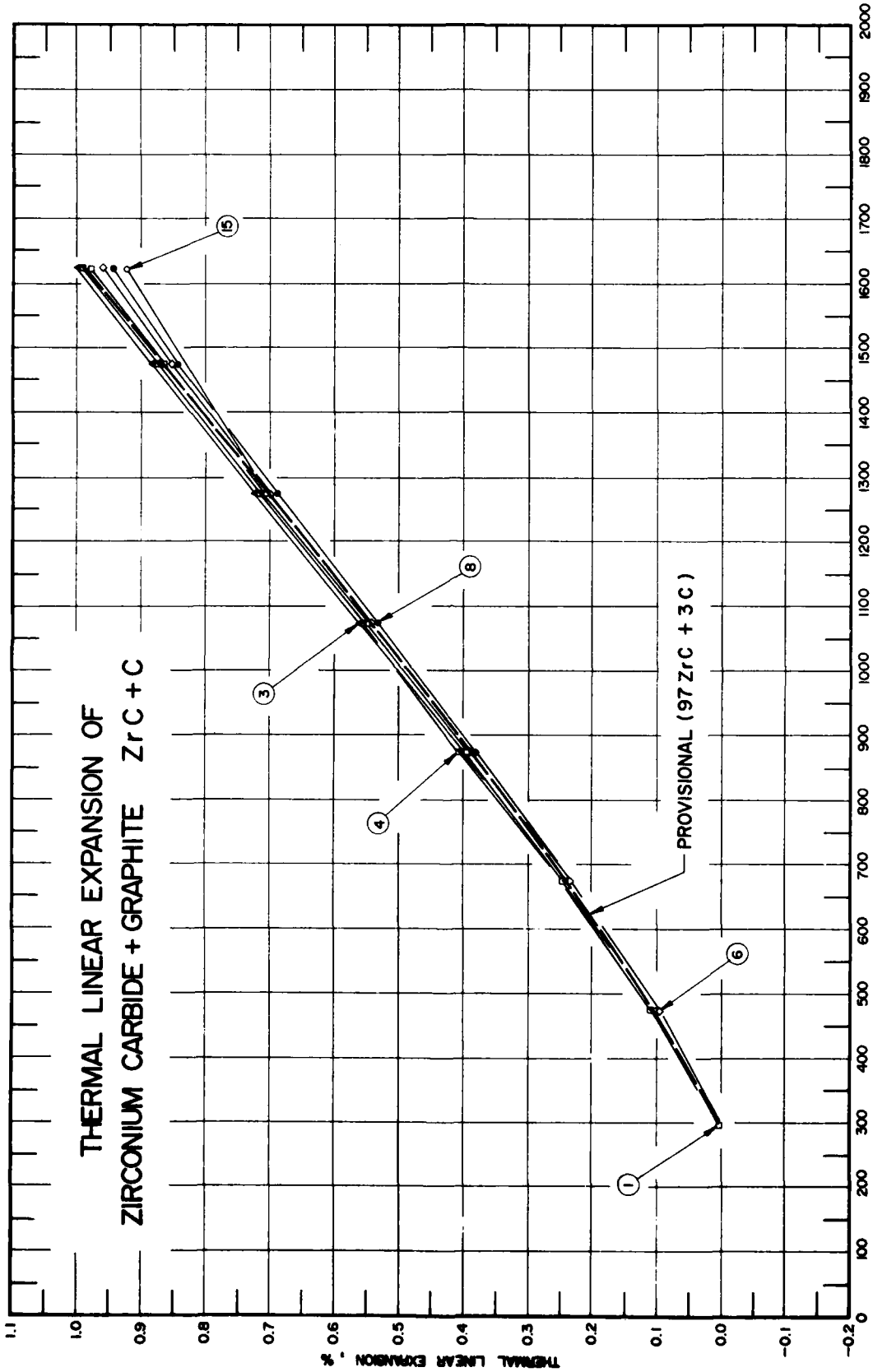

THERMAL LINEAR EXPANSION OF
ZIRCONIUM CARBIDE + GRAPHITE ZrC + C
PROVISIONAL (97 ZrC + 3C)
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
3
4
6
8
15

FIGURE 270

SPECIFICATION TABLE 270. THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE + GRAPHITE ZrC + C

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	430	Hasselman, D. P. H. and Shaffer, P. T. B.	1962		298-1623	Composite 10A	96.99 ZrC and 3.01 graphite (corresponds to 88.0 volume percent ZrC and 9.8 volume percent graphite); spectrographic analysis: 0.1-0.5 Fe, 0.01-0.05 Cr and Ca, and 0.005-0.01 B, Si, Ti; density of ZrC calculated from crystal structure data 6.70 g cm^{-3}; graphite particle size 70-100 mesh; ZrC from New Products Branch, The Carborundum Co.; in form of -325 mesh powder; graphite is regular mold stock from International Graphite and Electrode Co.; ZrC and graphite mixed in rotary mill, hot pressed at 2523 K and 2000 psi into 11.4 cm x 10.2 cm long bodies, cut to size and ground; porosity 2.2%; bulk density 6.09 g cm^{-3}; density of ZrC calculated from crystal structure data 6.70 g cm^{-3}; graphite bulk density is 1.77 g cm^{-3}; calculated density of graphite 1.915 g cm^{-3}; expansion measured perpendicular to hot pressing direction.
2*	430	Hasselman, D. P. H. and Shaffer, P. T. B.	1962		298-1623	Composite 20A	94.76 ZrC and 5.24 graphite (corresponds to 73.6 volume percent ZrC and 16.0 volume percent graphite); similar to the above specimen except due to lack of definitions between phases, volume analysis unreliable; porosity 9.6%; bulk density 5.29 g cm^{-3}.
3	430	Hasselman, D. P. H. and Shaffer, P. T. B.	1962		298-1623	Composite 30A	92.18 ZrC and 7.82 graphite (corresponds to 61.5 volume percent ZrC and 22.2 volume percent graphite); similar to above specimen; volume analysis is reliable; porosity 16.3%; bulk density 4.55 g cm^{-3}.
4	430	Hasselman, D. P. H. and Shaffer, P. T. B.	1962		298-1623	Composite 40A	82.99 ZrC and 17.01 graphite (corresponds to 51.3 volume percent ZrC and 40.8 volume percent graphite); similar to the above specimen except measured parallel to hot pressing direction; porosity 7.9%; bulk density 4.23 g cm^{-3}.
5*	430	Hasselman, D. P. H. and Shaffer, P. T. B.	1962		298-1623	Composite 40A	Similar to the above specimen except measured perpendicular to hot pressing air.
6	430	Hasselman, D. P. H. and Shaffer, P. T. B.	1962		298-1623	Composite 55A	79.93 ZrC and 20.07 graphite (corresponds to 50.2 volume percent ZrC and 46.2 volume percent graphite); similar to the above specimen; porosity 3.6%; bulk density 4.25 g cm^{-3}.
7*	430	Hasselman, D. P. H. and Shaffer, P. T. B.	1962		298-1623	Composite 60A	72.51 ZrC and 27.49 graphite (corresponds to 43.0 volume percent ZrC and 57.0 volume percent graphite); same as the above specimen except measured parallel to hot pressing direction; approximately 0.0% porosity; bulk density 3.97 g cm^{-3}.
8	430	Hasselman, D. P. H. and Shaffer, P. T. B.	1962		298-1623	Composite 60A	Same as the above specimen except measured perpendicular to hot pressing direction.
9*	432	Miccioli, B. R. and Julien, H. P.	1965	T	300-1623		90 volume percent ZrC; hot pressed specimen; density 6.09 g cm^{-3}; expansion measured perpendicular to pressing.
10*	432	Miccioli, B. R. and Julien, H. P.	1965	T	300-1623		80 volume percent ZrC; similar to the above specimen; density 5.29 g cm^{-3}.
11*	432	Miccioli, B. R. and Julien, H. P.	1965	T	300-1623		70 volume percent ZrC; similar to the above specimen; density 4.55 g cm^{-3}.
12*	432	Miccioli, B. R. and Julien, H. P.	1965	T	300-1623		60 volume percent ZrC; similar to the above specimen; density 4.23 g cm^{-3}.
13*	432	Miccioli, B. R. and Julien, H. P.	1965	T	300-1623		40 volume percent ZrC; similar to the above specimen; density 3.97 g cm^{-3}
14*	432	Miccioli, B. R. and Julien, H. P.	1965	T	300-1623		60 volume percent ZrC; similar to the above specimen; density 4.23 g cm^{-3}; expansion measured parallel to pressing direction.
15	432	Miccioli, B. R. and Julien, H. P.	1965	T	300-1623		40 volume percent ZrC; similar to the above specimen; density 3.97 g cm^{-3}.

* Not shown in figure.

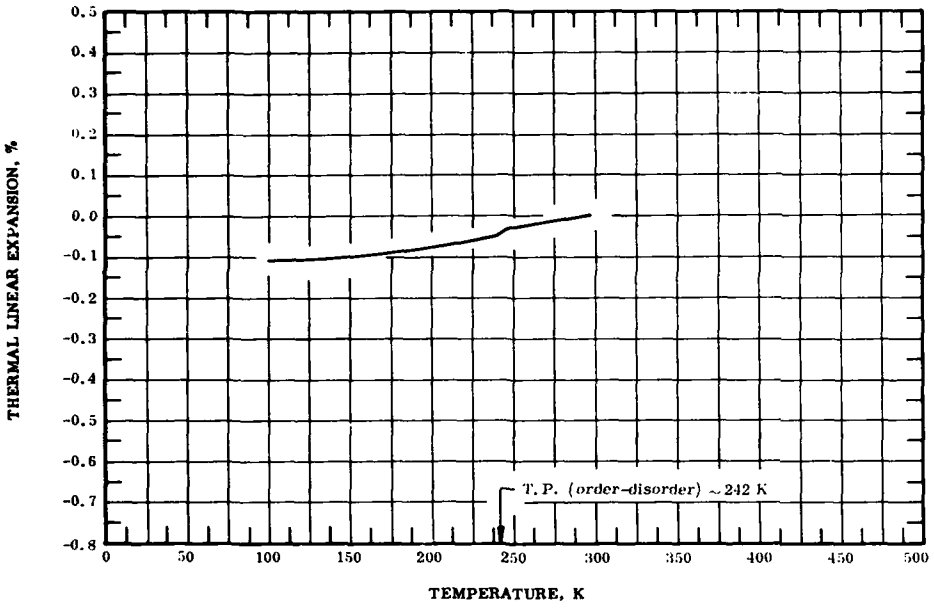
DATA TABLE 270. THERMAL LINEAR EXPANSION OF ZIRCONIUM CARBIDE + GRAPHITE ZrC + C

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
473	0.105
673	0.244
873	0.396
1073	0.550
1273	0.712
1473	0.867
1623	0.980
CURVE 2*	
293	0.000
473	0.102
673	0.244
873	0.400
1073	0.552
1273	0.712
1473	0.870
1623	0.986
CURVE 3	
293	0.000*
473	0.102
673	0.242
873	0.400
1073	0.562
1273	0.725
1473	0.883
1623	0.999
CURVE 4	
293	0.000*
473	0.101
673	0.245
873	0.398
1073	0.556
1273	0.714
1473	0.876
1623	0.992
CURVE 5*	
293	0.000
473	0.107
673	0.248
873	0.405
1073	0.562
1273	0.719
1473	0.877
1623	0.994
CURVE 6	
293	0.000*
473	0.098
673	0.238
873	0.392
1073	0.544
1273	0.700
1473	0.853
1623	0.963
CURVE 7*	
293	0.000
473	0.098
673	0.234
873	0.381
1073	0.534
1273	0.690
1473	0.839
1623	0.946
CURVE 8	
293	0.000*
473	0.107
673	0.249
873	0.404
1073	0.558
1273	0.711
1473	0.843
1623	0.923
CURVE 9*	
300	0.005
1273	0.711
1623	0.980
CURVE 10*	
300	0.005
1273	0.711
1623	0.986
CURVE 11*	
300	0.005
1273	0.725
1623	0.999
CURVE 12*	
300	0.005
1273	0.714
1623	0.992
CURVE 13*	
300	0.005
1273	0.690
1623	0.946
CURVE 14*	
300	0.005
1273	0.719
1623	0.993
CURVE 15	
300	0.005*
1273	0.710
1623	0.923

* Not shown in figure.

FIGURE AND TABLE NO. 271R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF AMMONIUM CHLORIDE NH_4Cl



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
100	-0.111	2.3
125	-0.105	2.6
150	-0.101	3.2
175	-0.089	4.0
200	-0.078	4.8
220	-0.066	7.0
225	-0.062	8.0
230	-0.058	9.2
235	-0.053	12.8
236	-0.052	13.7
237	-0.050	15.5
238	-0.048	19.0
239	-0.046	24.0
240	-0.044	28.0
241	-0.041	34.0
242†	-0.037	43.0
243	-0.033	32.0
244	-0.031	8.7
245	-0.030	8.0
250	-0.027	6.4
275	-0.011	6.0
293	0.000	6.0

† Order-disorder transition.

REMARKS

The recommended values are based on the measurements from curves 6-8. These are considered accurate to within ± 5%. The phase change from bcc to fcc at 459 K is reported in curve 1. The recommended values are represented approximately by the following equations:

$$\Delta L/L_0 = -0.185 + 1.412 \times 10^{-3}\, T - 9.135 \times 10^{-6}\, T^2 + 2.356 \times 10^{-8}\, T^3 \qquad (100\text{-}240\ K)$$

$$\Delta L/L_0 = -0.034 - 9.772 \times 10^{-4}\, T + 5.760 \times 10^{-6}\, T^2 - 6.930 \times 10^{-9}\, T^3 \qquad (245\text{-}293\ K)$$

The tabulated values for the coefficient of thermal expansion are based on the selected experimental data and are considered accurate to about ± 10% except the values near 242 K are very uncertain.

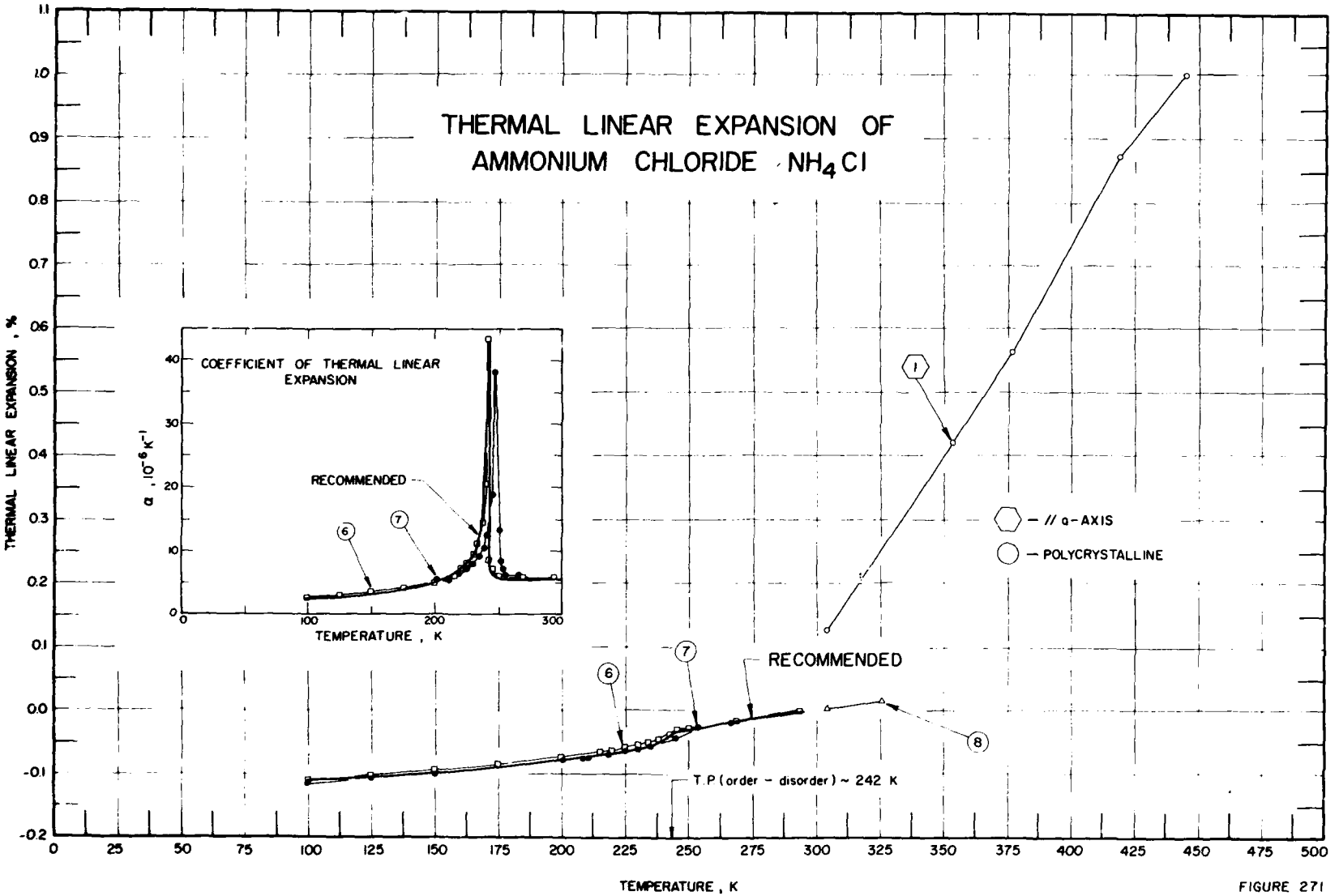

THERMAL LINEAR EXPANSION OF
AMMONIUM CHLORIDE NH_4Cl
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10^{-6} K^{-1}
RECOMMENDED
TEMPERATURE , K
// a-AXIS
POLYCRYSTALLINE
RECOMMENDED
T.P (order - disorder) ~ 242 K

FIGURE 271

SPECIFICATION TABLE 271. THERMAL LINEAR EXPANSION OF AMMONIA CHLORIDE NH_4Cl

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	344	Majumdar, A. J. and Roy, R.	1965	X	303-523		Chemically pure grade chemical; melted and powdered; expansion measured along a-axis; lattice parameter reported at 306 K as 3.878 Å; 3.873 Å at 293 K determined by graphical extrapolation; phase transition at 459 K from bcc to fcc; lattice parameter reported from 463 K to 523 K.
2*	742	Fredricks, G. E.	1969	E	233-242	Sample 1	Single crystal about 1 cm in length; expansion measured below phase transition.
3*	742	Fredricks, G. E.	1969	E	242-249		Same as the above specimen except expansion measured above phase transition.
4*	742	Fredricks, G. E.	1969	E	232-242	Sample 2	Similar to the above specimen except expansion measured below phase transition.
5*	742	Fredricks, G. E.	1969	E	242-248		Similar to the above specimen except expansion measured above phase transition.
6	743	Boiko, A. A.	1969	X	100-293	NH_4Cl	Dimensions: 10 mm diameter x 2 mm long; made by crushed powder annealed at 273 K for 8-12 hr, then mixed with vaseline and rammed into a hole in a brass cell; expansion measured with Cu radiation with β filter; lattice parameter reported at 100 K as 3.8260 Å.
7	743	Boiko, A. A.	1969	X	100-293	ND_4Cl	Similar to the above specimen except deuterium replaced the hydrogen; lattice parameter reported at 100 K as 3.8254 Å.
8	744	Sirdeshmukh, D. B. and Deshpande, V. T.	1969	X	304, 327		Flat-faced powder sample was prepared with analar grade British Drug House material; lattice parameter reported at 304.5 K as 3.8771 Å; 3.868 Å at 293 K determined by graphical extrapolation.

* Not shown in figure.

DATA TABLE 271. THERMAL LINEAR EXPANSION OF AMMONIA CHLORIDE NH_4Cl

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
303	0.129
377	0.568
418	0.878
444	1.007
	Å
463	6.532
493	6.540
523	6.547
CURVE 2*	
	$\Delta L/L_0$
233.45	-0.183
234.19	-0.177
234.99	-0.170
235.63	-0.165
236.21	-0.159
237.15	-0.149
237.86	-0.142
238.45	-0.135
238.72	-0.131
239.00	-0.128
239.33	-0.124
239.52	-0.121
239.86	-0.116
240.18	-0.112
240.48	-0.106
240.83	-0.101
241.04	-0.097
241.28	-0.092
241.52	-0.086
241.73	-0.081
241.98	-0.073
242.08	-0.069
242.14	-0.067
242.20	-0.065
242.26	-0.063
242.30	-0.060
CURVE 3*	
242.16	0.039
242.19	0.043
242.21	0.045
242.23	0.046
242.25	0.048

T	$\Delta L/L_0$
CURVE 3 (cont.)*	
242.31	0.050
242.37	0.051
242.45	0.052
242.58	0.054
242.68	0.055
242.82	0.057
242.99	0.058
243.19	0.060
243.55	0.063
244.12	0.067
244.66	0.070
245.50	0.075
246.96	0.083
248.54	0.091
249.84	0.098
CURVE 4*	
232.28	-0.195
234.79	-0.175
234.88	-0.174
235.70	-0.166
235.99	-0.164
236.21	-0.162
236.75	-0.156
237.01	-0.154
237.15	-0.152
237.75	-0.145
238.01	-0.142
238.15	-0.141
238.61	-0.136
238.81	-0.133
239.30	-0.127
239.38	-0.126
239.67	-0.122
240.18	-0.115
240.40	-0.112
240.44	-0.111
240.58	-0.108
241.07	-0.100
241.23	-0.097
241.48	-0.091
241.73	-0.085
242.01	-0.078
242.11	-0.075
242.18	-0.072
242.26	-0.069

T	$\Delta L/L_0$
CURVE 4 (cont.)*	
242.30	-0.067
242.35	-0.064
242.39	-0.059
242.40	-0.056
242.40	-0.052
242.40	-0.047
242.40	-0.037
CURVE 5*	
242.21	0.038
242.21	0.039
242.21	0.040
242.23	0.042
242.24	0.043
242.26	0.044
242.34	0.047
242.43	0.048
242.53	0.050
242.64	0.051
242.74	0.053
242.83	0.054
242.95	0.055
243.07	0.056
243.17	0.057
243.26	0.057
243.52	0.060
243.78	0.062
244.05	0.064
244.47	0.067
244.87	0.069
245.44	0.073
246.01	0.076
246.48	0.079
246.92	0.081
247.39	0.084
247.88	0.087
248.28	0.089
CURVE 6‡	
100	-0.110
125	-0.102
150	-0.094
175	-0.084
200	-0.073
215	-0.064

T	$\Delta L/L_0$
CURVE 6 (cont.)‡	
220	-0.061
225	-0.057
230	-0.053
233	-0.049
237	-0.044
239	-0.041
241	-0.034*
242	-0.032*
245	-0.029
250	-0.026
268	-0.015
293	0.000
CURVE 7‡	
100	-0.114
125	-0.107
150	-0.099
175	-0.089*
201	-0.076
211	-0.071
218	-0.066
225	-0.062
[illegible]0	-0.058
235	-0.053
238	-0.050*
241	-0.047*
245	-0.040
247	-0.035*
250	-0.027*
249	-0.028*
251	-0.026*
253	-0.025
256	-0.023*
267	-0.016
293	0.000
CURVE 8	
304.5	0.006
327	0.019

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

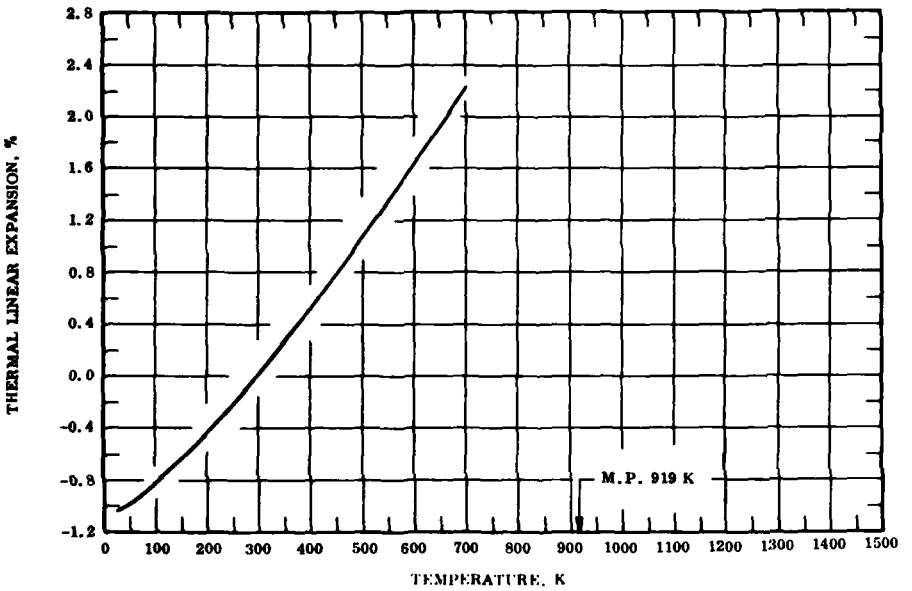
DATA TABLE 271. COEFFICIENT OF THERMAL LINEAR EXPANSION OF AMMONIA CHLORIDE NH_4Cl

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 6‡	
100	2.8
125	3.0
150	3.6
175	4.2
200	5.0
215	6.3
220	7.3
225	8.2
230	9.7
233	11.3
237	14.6
239	20.7
241	43.4
242	8.8
245	7.1
250	6.2
268	6.0
293	6.0
CURVE 7‡	
100	2.7*
125	3.0*
150	3.6*
175	4.4*
201	5.3
211	5.9
218	6.5
225	7.3
230	8.1
235	9.3
238	10.7
241	12.9
245	19.0
247	38.3
250	13.4
249	9.6*
251	8.3
253	7.1
256	6.3
267	6.1
293	6.2*

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 272R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF CESIUM CHLORIDE CsCl



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
25	-1.013	10.5
50	-0.966	24.7
75	-0.895	31.5
100	-0.811	35.9
150	-0.618	40.5
200	-0.412	42.4
250	-0.195	44.4
293	0.000	46.2
300	0.032	46.6
400	0.521	51.1
500	1.055	55.8
600	1.640	61.1
700	2.277	66.3

REMARKS

The recommended values are based on the data for high purity samples and are considered accurate to within ±3%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -1.181 + 3.475 \times 10^{-3}\, T + 1.747 \times 10^{-6}\, T^2 + 4.918 \times 10^{-10}\, T^3 \qquad (150\text{-}700\ K)$$

The tabulated values for the coefficient of thermal expansion are based on the selected experimental data. These values are considered accurate to about ±5%.

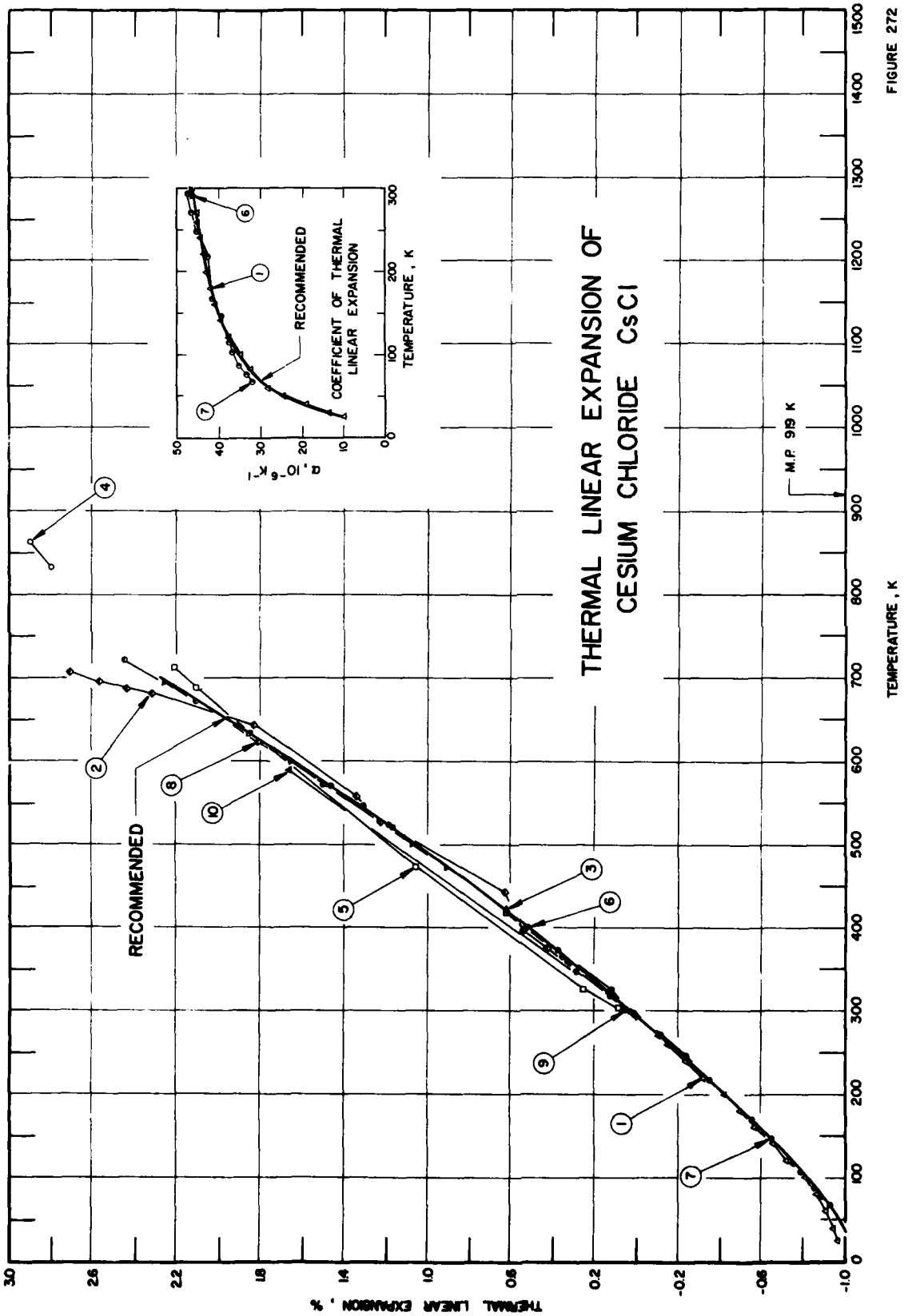

THERMAL LINEAR EXPANSION OF
CESIUM CHLORIDE CsCl
RECOMMENDED
M.P. 919 K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
RECOMMENDED
α, 10⁻⁶ K⁻¹
TEMPERATURE, K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K

FIGURE 272

SPECIFICATION TABLE 272. THERMAL LINEAR EXPANSION OF CESIUM CHLORIDE CsCl

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	619	Bailey, A.C. and Yates, B.	1967	I	25-270		Specimen cut from single crystal grown from melt by Prof. A. Smakula at Massachusetts Institute of Technology, Cambridge, Mass.
2	745	Morlin, Z. and Tremmel, J.	1966	X	295-707		Specimen prepared from Merck pro-analysis CsCl in vacuum at 2×10^{-5} torr by evaporation from a molybdenum boat; transition from α to β phase observed beginning at 673 K and complete at 733 K; lattice parameter reported at 295 K as 4.118 Å; 4.117 Å at 293 K determined by graphical extrapolation.
3	746	Christian, J.M. and Lynch, D.W.	1964	L	323,423		Average grain diameter 1 mm; polycrystalline low temperature phase of CsCl; dimensions: rod 1.27 cm diameter x 4.08 cm long; melted in air, poured into brass mold coated with colloidal carbon.
4	746	Christian, J.M. and Lynch, D.W.	1964	L	834,863		Similar to the above specimen; at high-temperature NaCl phase; reported error is 10%.
5	344	Majumdar, A.J. and Roy, R.	1965	X	303-758		C.P. grade chemical, melted and powdered; lattice parameter reported at 303 K as 4.123 Å; 4.119 Å at 293 K determined by graphical extrapolation.
6	625	Srivastava, K.K. and Merchant, H.D.	1972	X	293-695		*No details given.*
7	626	Rapp, J.E. and Merchant, H.D.	1972	L	68-572		Crystal orientation was <1, 1, 1>; dimensions were 5 x 5 x 25 mm; smoothed data.
8	747	Fullam, H.T.	1972		293-723		Specimen was 99.9+ pure with total impurities <0.01 wt.% of C, Na, and K.
9	632	Bridgman, P.W.	1932		303,348		Cylindrical specimen of 9.5 mm diameter x 9.5-15.8 mm long; the lever piezometer method was used to measure expansion.
10	664	Whittemore, P.O.	1962	L	293,593		Cylindrical specimen of 15.8 mm diameter x 25.4 mm long; specimen made by pressing reagent grade chemicals in a steel mold at 703 kg/cm^2; original length measured by micrometer to 25.4 μm; expansion measurement taken with two cylinders 0.001 in. placed end to end.

DATA TABLE 272. THERMAL LINEAR EXPANSION OF CESIUM CHLORIDE CsCl

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
25	-0.9892
30	-0.9842*
40	-0.9706
50	-0.9510*
60	-0.9265
80	-0.8699
100	-0.8043
120	-0.7331
140	-0.6575
160	-0.5785
180	-0.4967
200	-0.4127
220	-0.3267
240	-0.2391
260	-0.1501
270	-0.1049
CURVE 2	
295	0.011
375	0.436
399	0.530
442	0.627
529	1.244
559	1.354
643	1.837
680	2.337
687	2.459
697	2.587
707	2.711
CURVE 3	
323	0.143
423	0.621
CURVE 4	
834	2.805
863	2.907
CURVE 5	
303	0.0971
325	0.2671
473	1.0682
633	1.8451
687	2.1122
713	2.2093
	Å
738	7.040
758	7.044
CURVE 6‡	
293	0.000
300	0.032
400	0.523
500	1.062
600	1.648
695	2.245
CURVE 7‡	
68	-0.930
78	-0.897
88	-0.862
107	-0.794
117	-0.757
145	-0.648
169	-0.551
CURVE 7 (cont.)‡	
218	-0.343
245	-0.222
270	-0.108
293	0.000*
295	0.009*
320	0.129
367	0.359
420	0.627
473	0.903
523	1.174
547	1.309
572	1.452
CURVE 8‡	
293	0.000*
CURVE 8 (cont.)‡	
323	0.138
373	0.378
423	0.639*
473	0.915
523	1.198
573	1.493
623	1.802
673	2.123
723	2.458
CURVE 9	
303	0.049
348	0.272
CURVE 10	
293	0.00*
593	1.66

DATA TABLE 272. COEFFICIENT OF THERMAL LINFAR EXPANSION OF CESIUM CHLORIDE CsCl

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
25	10.0
30	13.6
40	19.6
50	24.5
60	28.3
80	32.8
100	35.6
120	37.8
140	39.5
160	40.9
180	42.0
200	43.0
220	43.8
240	44.5
260	45.2
270	45.6
CURVE 6‡	
293	46.2
300	46.6
400	51.6*
500	56.2*
600	60.9
695	64.7*
CURVE 7‡	
68	32.8
78	33.5
88	35.3
107	36.7
117	37.7
145	39.7
169	41.4
218	43.7
CURVE 7 (cont.)‡	
245	45.4
270	46.4
293	47.1
295	47.4
320	48.2*
367	49.9*
420	51.2*
473	52.9*
523	55.4*
547	56.7*
572	58.4*
CURVE 8*,‡	
293	45.4
323	46.6
373	49.5
CURVE 8 (cont.)‡	
423	54.9
473	55.5
523	57.6
573	60.5
623	63.0
673	65.3
723	68.7

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

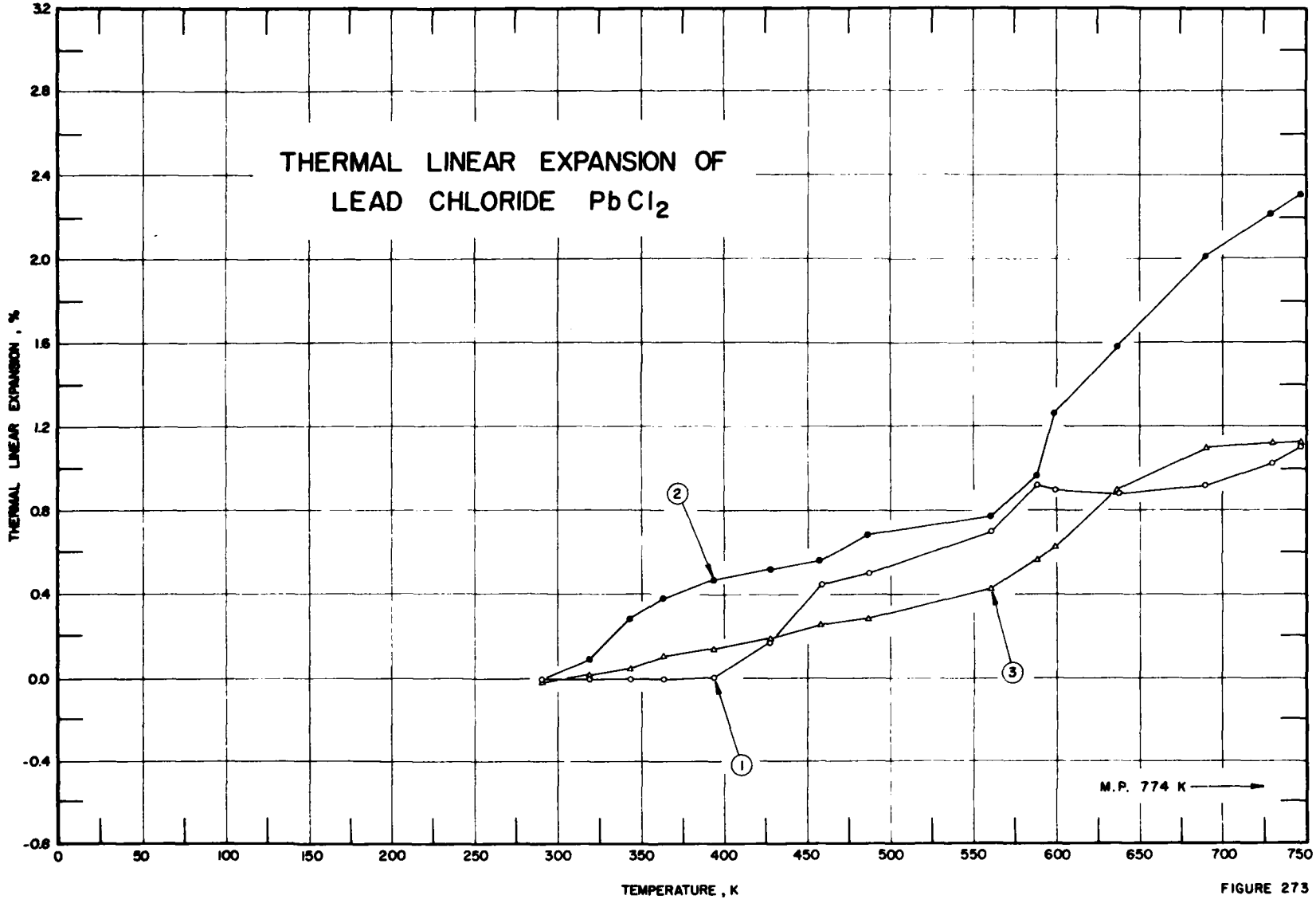

THERMAL LINEAR EXPANSION OF
LEAD CHLORIDE PbCl2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
M.P. 774 K
1
2
3
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
-0.4
-0.8
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750

FIGURE 273

SPECIFICATION TABLE 273. THERMAL LINEAR EXPANSION OF LEAD CHLORIDE $PbCl_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	295	Hsu, Y.T.	1967	X	291-748		Reagent quality powdered orthorhombic crystals in 0.3 mm diameter capillary; expansion measured along a-axis; lattice parameter measured along a-axis; lattice parameter reported at 293 K as 4.530 Å.
2	295	Hsu, Y.T.	1967	X	291-748		The above specimen; expansion measured along b-axis; lattice parameter reported at 291 K as 7.613 Å; 7.614 Å at 293 K determined by graphical extrapolation.
3	295	Hsu, Y.T.	1967	X	291-748		The above specimen; expansion measured along c-axis; lattice parameter reported at 291 K as 9.042 Å; 9.041 Å at 293 K determined by graphical extrapolation.

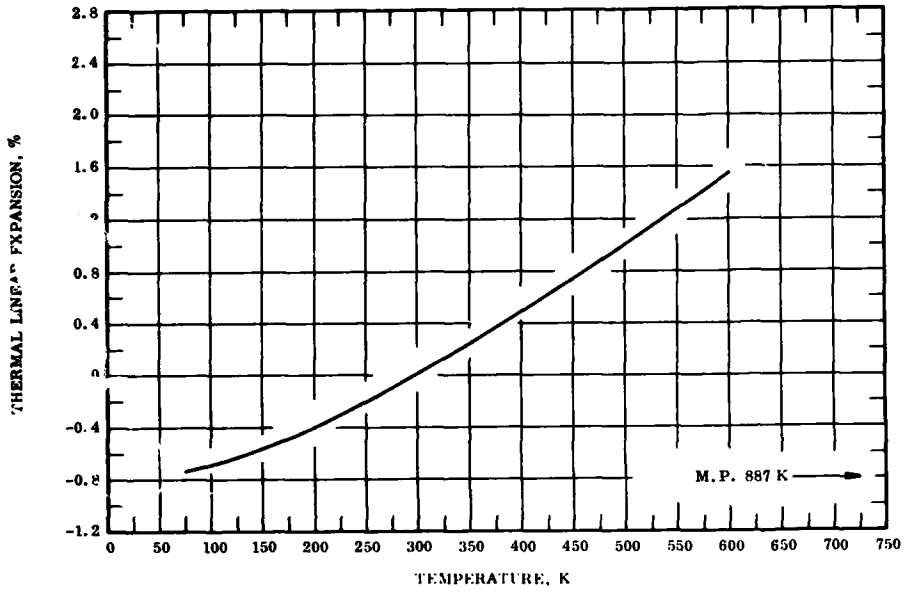
DATA TABLE THERMAL LINEAR EXPANSION OF LEAD CHLORIDE $PbCl_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3	
291	0.000	291	0.000*	291	-0.001
318	0.000	318	0.105	318	0.020
343	0.000	343	0.289	343	0.054
363	0.000	363	0.381	363	0.109
393	0.011	393	0.473	393	0.142
428	0.177	428	0.525	428	0.197
458	0.442	458	0.565	458	0.253
487	0.508	487	0.696	487	0.286
561	0.706	561	0.775	561	0.430
588	0.927	588	0.972	588	0.573
599	0.905	599	1.274	599	0.629
637	0.883	637	1.589	637	0.894
691	0.927	691	2.023	691	1.104
731	1.038	731	2.220	731	1.126
748	1.104	748	2.298	748	1.126

* Not shown in figure.

FIGURE AND TABLE NO. 274R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF LITHIUM CHLORIDE LiCl



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
75	-0.761	18.6
100	-0.706	25.2
150	-0.558	33.0
200	-0.381	37.8
250	-0.183	41.2
293	0.000	43.7
300	0.031	44.0
350	0.256	46.2
400	0.491	47.9
450	0.736	50.1
500	0.993	52.4
550	1.259	54.3
600	1.539	57.4

REMARKS

The recommended values are based on the most recent measurement (curve 1). These values are considered accurate to within ±5% and are represented approximately by the following equations:

$$\Delta L/L_0 = -0.854 + 0.427 \times 10^{-3}\, T + 1.232 \times 10^{-5}\, T^2 - 1.306 \times 10^{-8}\, T^3 \quad (75\text{–}293\ K)$$

$$\Delta L/L_0 = -1.140 + 3.458 \times 10^{-3}\, T + 1.294 \times 10^{-6}\, T^2 + 6.408 \times 10^{-10}\, T^3 \quad (293\text{–}600\ K)$$

The tabulated values for the coefficient of thermal expansion are based on the selected experimental data and are considered accurate to about ±7%.

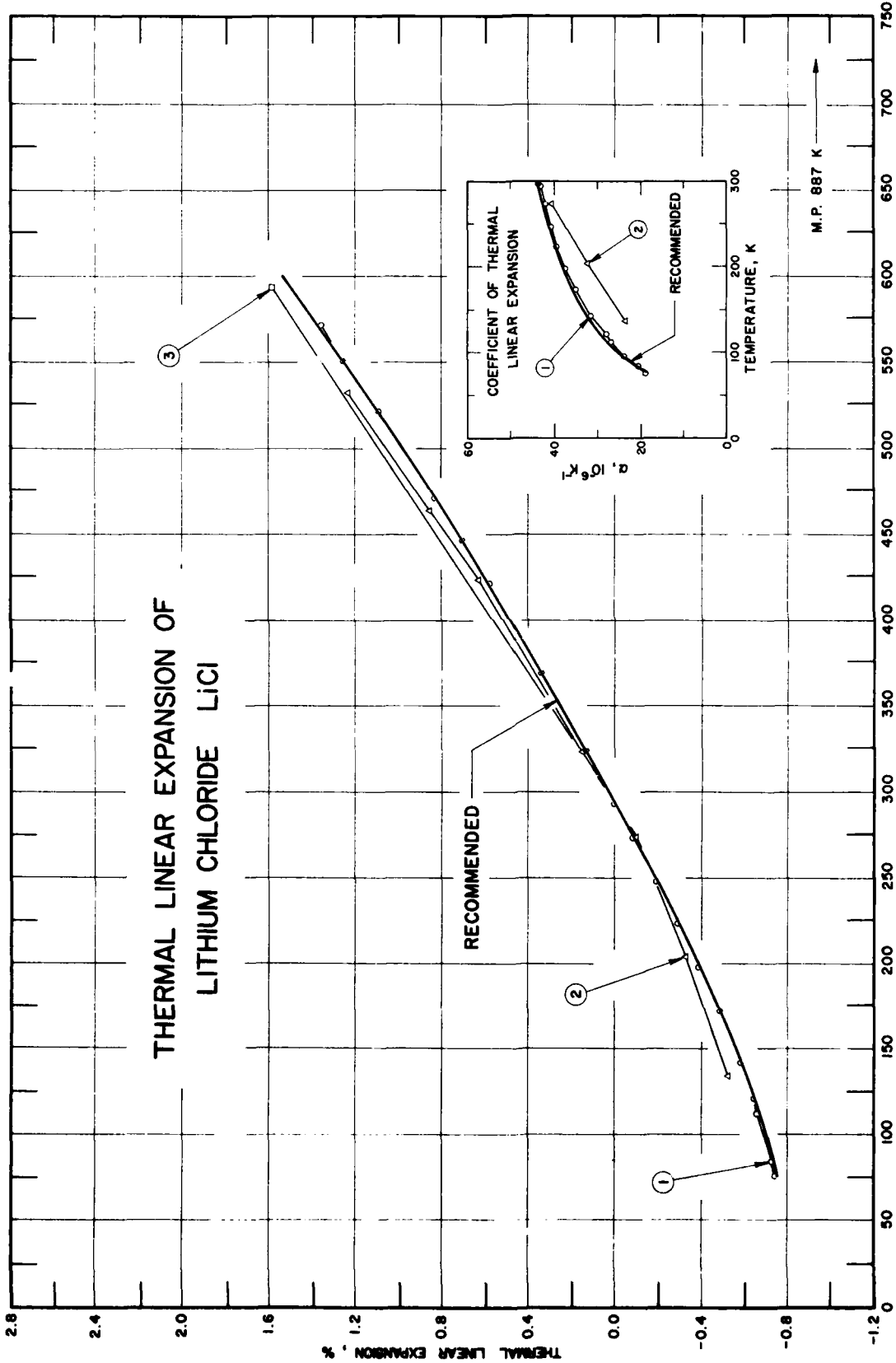

THERMAL LINEAR EXPANSION OF
LITHIUM CHLORIDE LiCl
RECOMMENDED
M.P. 887 K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
RECOMMENDED
α, 10⁶K⁻¹
TEMPERATURE, K

FIGURE 274

SPECIFICATION TABLE 274. THERMAL LINEAR EXPANSION OF LITHIUM CHLORIDE LiCl

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	626	Rapp, J.E. and Merchant, H.D.	1972	L	75-571		Crystal orientation was <1,0,0>; dimensions were 5 x 5 x 33 mm; smoothed data.
2	663	Von Trost, K.F.	1963		137-532		No details given.
3	664	Whittemore, D.O.	1962	L	293,593		Dimensions: cylindrical, 1.27 cm diameter x 2.54 cm long; specimen made by pressing reagent grade chemicals in a steel mold at 277 kg cm^{-2}; original length measured by micrometer to 2.5 μm; measurements taken with two cylinders placed end to end.

DATA TABLE 274. THERMAL LINEAR EXPANSION OF LITHIUM CHLORIDE LiCl

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 1 (cont.)‡		CURVE 2 (cont.)‡		CURVE 3	
75	-0.754	223	-0.289	471	0.830	204	-0.335	293	0.00*
84	-0.736	247	-0.193	522	1.094	273	-0.084	593	1.58
95	-0.711*	274	-0.081	551	1.250	293	0.000*		
112	-0.669	293	0.000	571	1.360	324	0.142		
121	-0.644	294	0.004*			423	0.633		
142	-0.581	323	0.132	CURVE 2‡		463	0.844		
172	-0.481	369	0.340			532	1.232		
197	-0.390	421	0.584	137	-0.522				

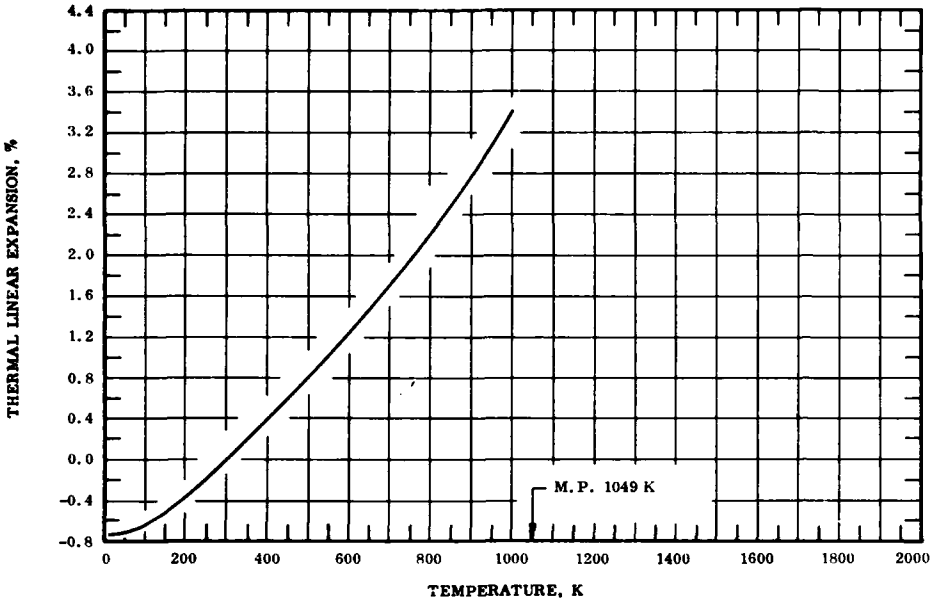
DATA TABLE 274. COEFFICIENT OF THERMAL LINEAR EXPANSION OF LITHIUM CHLORIDE LiCl

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 1 (cont.)‡		CURVE 2 (cont.)‡	
75	18.9	223	39.7	471	50.2*	204	32.3
84	20.8	247	40.8	522	53.4*	273	40.3
95	23.9	274	42.1	551	54.5*	293	43.8*
112	26.4	293	43.1	571	55.7*	324	47.9*
121	27.9	294	43.5			423	51.2*
142	31.8	323	44.4*	CURVE 2‡		463	54.7*
172	35.0	369	46.0*			532	57.7*
197	37.8	421	48.0*	137	23.6		

‡ Not shown in figure.
* Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 275R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF POTASSIUM CHLORIDE KCl



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
10	-0.738	0.1
20	-0.737	0.7
30	-0.736	2.5
40	-0.732	6.4
50	-0.723	10.8
75	-0.685	20.7
100	-0.626	25.8
150	-0.487	30.5
200	-0.328	33.3
250	-0.155	35.4
293	0.000	36.5
300	0.026	36.6
400	0.407	39.6
500	0.818	42.6
600	1.259	45.7
700	1.735	49.5
800	2.250	53.5
900	2.806	57.6
1000	3.404	62.1

REMARKS

The recommended values are based on the data for high-purity samples. These values are considered accurate to within ±3% and can be represented approximately by the following equation:

$$\Delta L/L_0 = -0.951 + 2.889 \times 10^{-3}\, T + 1.106 \times 10^{-5}\, T^2 + 3.588 \times 10^{-10}\, T^3 \quad (150\text{-}1000\ K)$$

The tabulated values for the coefficient of thermal expansion are based on the selected experimental data and are considered accurate to about ±5%.

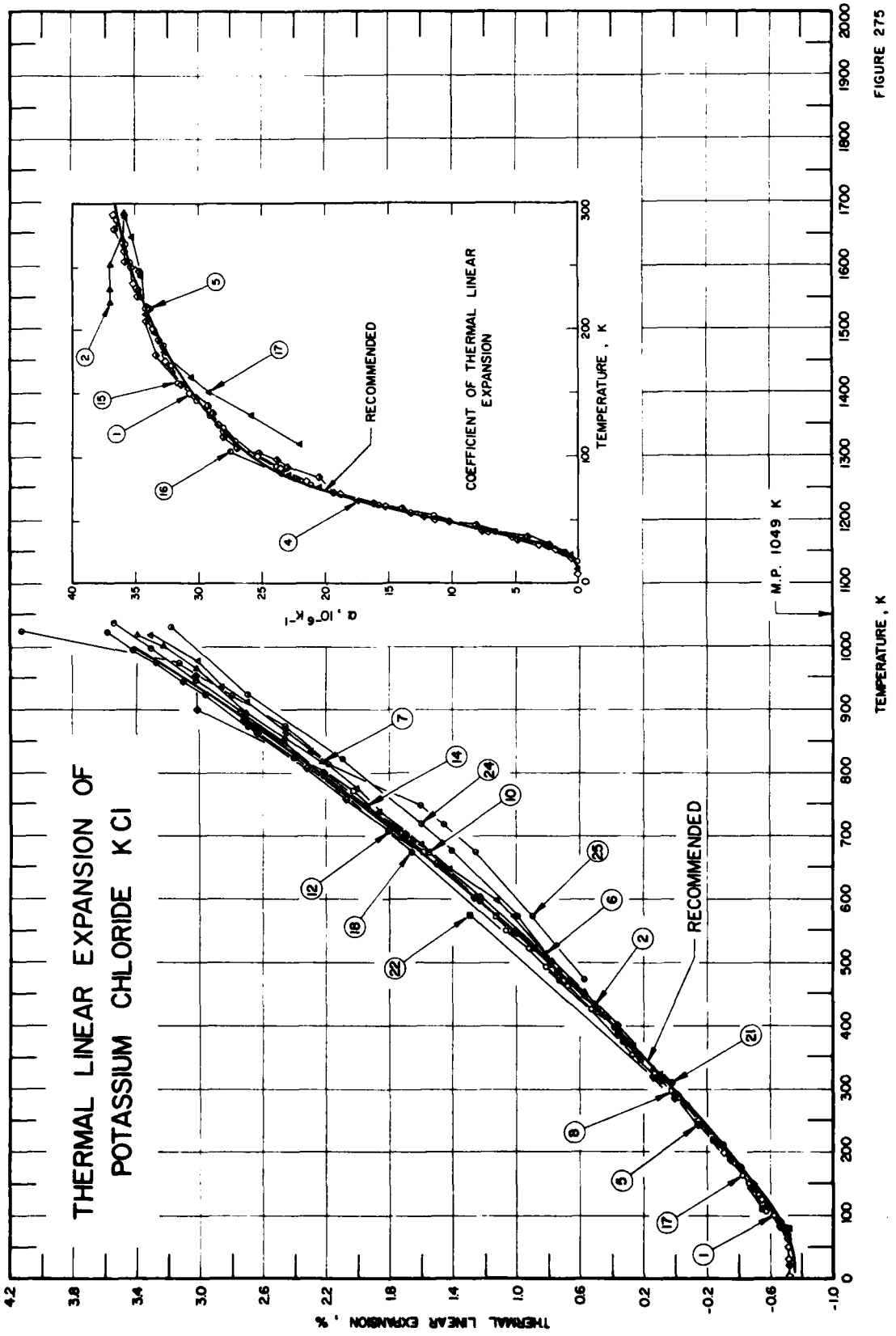

THERMAL LINEAR EXPANSION OF
POTASSIUM CHLORIDE K Cl
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
M.P. 1049 K
RECOMMENDED
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K
RECOMMENDED

FIGURE 275

SPECIFICATION TABLE 275. THERMAL LINEAR EXPANSION OF POTASSIUM CHLORIDE KCl

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	478	Meincke, P. P. N. and Graham, G. N.	1965	I	7-290		Specimen 4.08 cm long, 2.54 cm diameter with an axial hole of 1.27 cm diameter; crystal supplied by the Harshaw Chemical Co.; smoothed data; reported error <5%.
2	322	Combes, L. S., Ballard, S. S., and McCarthy, K. A.	1951	L	223-473		Sample furnished by the Harshaw Chemical Co. of Cleveland, Ohio; bar specimen.
3*	322	Combes, L. S., et al.	1951	L	223-473		The above specimen; average values.
4*	479	White, G. K.	1965	C	6-85		Cylindrical specimen of 2 cm diameter x 5 cm long; specimen grown from melt of reagent grade material; data smoothed by author; this curve is here reported using 6 K as the reference temperature at which $\Delta L/L_0 = 0$; reported error 1.0%.
5	480	Yates, B. and Panter, C. H.	1962	I	24-279		Single crystal from Hilger and Watts Ltd., London; grown from material 99.8% pure; expansion observed with cadmium green light (5085.8 Å).
6	752	von Guerard, B., Peisl, H., and Waidelich, W.	1968	X	321-1019		Expansion measured using $CuK\alpha_1$ x-radiation.
7	752	von Guerard, B., et al.	1968	I	294-1019		The above specimen.
8	481	McKinstry, H. A.	1960	X	298-872		Single crystal from Harshaw Co.; freshly cleaved surface; lattice parameters extrapolated to reduce systematic errors; first run A; lattice parameter reported at 298 K as 6.2922 Å; 6.2910 Å at 293 K determined by graphical extrapolation.
9*	481	McKinstry, H. A.	1960	X	296-873		The above specimen; extrapolated lattice parameters recorded; first run B; lattice parameter reported at 296 K as 6.2917 Å; 6.2910 Å at 293 K determined by graphical extrapolation.
10	481	McKinstry, H. A.	1960	X	298-673		Powdered sample of single crystal from Harshaw Co.; ground and heated to 450 C; cooled in furnace; the extrapolated lattice parameters recorded; second run A; lattice parameter reported at 298 K as 6.2920 Å; 6.2909 Å at 293 K determined by graphical extrapolation.
11*	481	McKinstry, H. A.	1960	X	297-572		The above specimen; second run B; lattice parameter reported at 298 K as 6.2920 Å; 6.2910 Å at 293 K determined by graphical extrapolation.
12	481	McKinstry, H. A.	1960	O	297-887		Single crystal of KCl used; average coefficient of thermal expansion from the previous temperature to the one in question agrees well with x-ray results; divergence of two results increased with temperature; reported error <2%.
13*	481	McKinstry, H. A.	1960	I	369-887		The above specimen; another run average coefficient of thermal expansion from the previous temperature to the one in question, calculated from interferometer fringes; reported error <2%.
14	753	Enck, F. D., Engle, D. G., and Marks, K. I.	1962	I	299-1038		Data average of results taken from four specimens cut from single crystal; zero-point correction is -0.022%.
15*	754	Rubin, T., Johnston, H. L., and Altman, H. W.	1962	I	16-288		Cylindrical specimen of 0.4955 cm long at 298 K; large pieces of potassium chloride were obtained from the Harshaw Chemical Co.; cut into three pillars; then filed to approximately the same length.
16*	755	Schuck, D. E.	1963	X	30-104		Single crystal, purchased from Harshaw Chemical Co.; (16,6,4) plane, with $MoK\alpha$ radiation used; this curve is here reported using 30 K as the reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

SPECIFICATION TABLE 275. THERMAL LINEAR EXPANSION OF POTASSIUM CHLORIDE KCl (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
17	756	Srinivasan, R.	1955		109-550.6		Pure potassium chloride.
18	621	Pathak, P.D. and Vasavada, N.G.	1970	X	293-1021		Powder specimen.
19*	757	Awad, F.C. and Gugan, D.	1971	X	10-80		Optical purity sample, obtained from Harshaw Chemicals Ltd.; single crystal samples, two runs made on sample, these results were smoothed, and rounded values of thermal expansion coefficient given; error limits of ±2% on thermal expansion coefficient; this curve is here reported using 10 K as the reference temperature at which $\Delta L/L_0 = 0$.
20*	623	White, G.K. and Collins, J.C.	1973	E	3-283		Dimensions: cylindrical, 20 mm diameter x 50.8 mm long; specimen grown by Mr. J.S. Cook from reagent grade material containing a few ppm of hydroxyl ions and divalent cations; data reported from 65-283 K was obtained from G.K. White, 1965; this curve is here reported using 3.452 K as the reference temperature at which $\Delta L/L_0 = 0$.
21	625	Srivastava, K.K. and Merchant, H.D.	1972	X	293-952		No details given.
22	626	Rapp, J.E. and Merchant, H.D.	1972	L	76-572		Crystal orientation was <1,0,0>; dimensions were 5 x 5 x 50 mm; smoothed data.
23*	759, 760	Smirnov, M.V., Vasilevskaya, M.M., and Burov, G.V.	1970	X	293,1034		Impurities 0.003 Ca, 0.0001 Mg; monocrystal; zero-point correction is -0.09%.
24	759, 760	Smirnov, M.V., et al.	1970	L	293-1032		Impurities 0.001 Ca, 0.001 Mg; chemically pure; zero-point correction is -0.09%.
25	759, 760	Smirnov, M.V., et al.	1970		293-1023		Impurities 0.001 Ca, 0.003 Mg; chemically pure, remelted; pyconmetric method; zero-point correction is -0.09%.
26*	663	Von Trost, K.F.	1963		140-605		No details given.
27*	664	Whittemore, P.O.	1962	L	293,593		Cylindrical specimen of 1.27 cm diameter x 2.54 cm long; specimen formed by pressing reagent grade chemicals into a steel mold at 703 kg/cm^2; original length measured by micrometer to 25.4 μm; measurement taken with two cylinders placed end to end.

* Not shown in figure.

DATA TABLE 275. THERMAL LINEAR EXPANSION OF POTASSIUM CHLORIDE KCl

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
7	-0.737
8	-0.737*
9	-0.737*
10	-0.737*
11	-0.737*
12	-0.737*
13	-0.737*
14	-0.737*
15	-0.737*
16	-0.737*
17	-0.737*
18	-0.737*
19	-0.737*
20	-0.737*
22	-0.736*
24	-0.736*
26	-0.736*
28	-0.736*
30	-0.735
32	-0.734*
34	-0.733*
36	-0.732*
38	-0.731*
40	-0.730*
45	-0.726*
50	-0.721
55	-0.714*
60	-0.707*
65	-0.704*
70	-0.699
80	-0.679*
90	-0.656
100	-0.632
125	-0.564
150	-0.490
175	-0.411
200	-0.328
250	-0.156
290	-0.011
CURVE 2‡	
223	-0.256
233	-0.219
253	-0.145*
273	-0.072
293	0.000
313	0.072
333	0.144
353	0.217
373	0.291
393	0.365
413	0.439
433	0.513
453	0.587
473	0.661
CURVE 3*,†	
223	-0.185
293	0.000
373	0.296
473	0.666
CURVE 4*,‡	
6	0.000
7	0.000
8	0.000
10	0.001
12	0.002
14	0.005
16	0.010
18	0.018
20	0.030
22	0.048
24	0.073
26	0.108
28	0.154
30	0.212
65	0.383
75	0.573
85	0.791
CURVE 5‡	
24	-0.739
30	-0.738*
34	-0.736*
37	-0.735*
41	-0.733*
45	-0.730*
49	-0.726*
53	-0.721*
58	-0.715*
63	-0.707
68	-0.699*
68	-0.699*
72	-0.692*
79	-0.678*
84	-0.668
86	-0.664*
91	-0.653*
92	-0.650*
96	-0.641*
100	-0.632*
102	-0.627*
104	-0.622*
106	-0.616*
107	-0.614*
115	-0.592
116	-0.589*
125	-0.564*
134	-0.538*
138	-0.526*
142	-0.514
144	-0.508*
148	-0.496*
156	-0.471*
158	-0.465*
168	-0.434*
176	-0.408*
180	-0.395*
188	-0.368
192	-0.355*
198	-0.335*
201	-0.325*
206	-0.308*
216	-0.274
226	-0.240*
229	-0.229*
236	-0.205*
238	-0.198*
246	-0.169
247	-0.166*
254	-0.141*
258	-0.127*
263	-0.109*
272	-0.077*
279	-0.051
CURVE 6	
321	0.10
368	0.27
382	0.32*
417	0.46
445	0.57
449	0.58*
472	0.68*
513	0.83
520	0.87*
573	1.09
595	1.19
626	1.33*
646	1.41
662	1.48*
685	1.60
714	1.73*
718	1.76*
739	1.86
749	1.91*
768	1.98*
771	1.99*
775	2.01
779	2.04*
801	2.15*
814	2.21*
834	2.30
854	2.42*
862	2.46
876	2.53*
882	2.59*
899	2.67*
910	2.71
930	2.84*
934	2.86
965	3.03*
969	3.06*
978	3.10
999	3.23*
1019	3.34
CURVE 7	
294	0.01*
816	2.23
855	2.45
861	2.48*
876	2.56*
899	2.70
908	2.75*
911	2.75*
930	2.87*
934	2.89*
965	3.09
970	3.09*
979	3.15
1000	3.28
1019	3.39
CURVE 8	
298.30	0.020
373.45	0.299*
473.20	0.698
572.95	1.125
672.95	1.590
773.20	2.090
773.20	2.090
872.95	2.640
CURVE 9*	
296.40	0.020
296.70	0.022
373.95	0.303
375.70	0.307
422.80	0.492
623.80	1.35
722.95	1.83
823.70	2.35
873.95	2.63
CURVE 10	
298.45	0.019*
373.20	0.279*
423.40	0.485
472.70	0.681*
523.70	0.891
CURVE 10 (cont.)	
574.20	1.11*
673.95	1.57
CURVE 11*	
297.95	0.014
301.20	0.024
374.20	0.303
421.95	0.489
422.70	0.492
473.70	0.673
522.70	0.918
572.95	1.14
CURVE 12‡	
297.6	0.0160*
369.5	0.2737*
425.3	0.4997*
485.1	0.7361
545.5	1.0049
600.3	1.2601
654.8	1.5247
709.7	1.8044
759.4	2.0706
808.2	2.3392
862.2	2.6405
887.0	2.7326
CURVE 13*,‡	
369.5	0.2117
425.3	0.5405
485.1	0.7759
545.5	1.0200
600.3	1.2909
654.8	1.5460
709.7	1.8054
759.4	2.0826
808.2	2.3374
862.2	2.5969
887.0	2.7176
CURVE 14	
299	0.022*

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 275. THERMAL LINEAR EXPANSION OF POTASSIUM CHLORIDE KCl (continued)

T	$\Delta L/L_0$
CURVE 14 (cont.)	
348	0.205
398	0.396
448	0.593*
498	0.799
548	1.014*
598	1.237
648	1.468
698	1.708
748	1.956
798	2.214
848	2.479
898	2.753
948	3.035
998	3.327
1038	3.565
CURVE 15*,‡	
16.560	-0.745
22.74	-0.745
28.80	-0.743
34.83	-0.741
41.32	-0.737
50.32	-0.728
61.33	-0.713
70.95	-0.696
78.95	-0.680
83.050	-0.672
91.74	-0.651
101.83	-0.627
111.62	-0.601
120.99	-0.575
132.00	-0.543
144.157	-0.507
157.83	-0.465
172.68	-0.418
187.91	-0.368
202.70	-0.319
217.68	-0.268
233.86	-0.213
252.72	-0.146
266.288	-0.098
272.15	-0.077
286.77	-0.024
288.51	-0.017

T	$\Delta L/L_0$
CURVE 16*,†,‡	
30	0.000
40	0.049
87	0.076
104	0.119
CURVE 17‡	
109.0	-0.587
131.8	-0.533
150.7	-0.481
163.7	-0.442
181.2	-0.386
197.6	-0.332*
212.2	-0.283
243.0	-0.177*
273.2	-0.072*
288.2	-0.018
329.5	0.134
364.2	0.268
396.8	0.398*
429.9	0.532
461.7	0.665
493.9	0.806
523.1	0.940
550.6	1.069
CURVE 18‡	
293	0.000*
324	0.116*
376	0.318
474	0.721
573	1.161*
674	1.641
773	2.143
823	2.409
873	2.684
923	2.971
946	3.109
971	3.265
996	3.428
1021	3.597
CURVE 19*,†,‡	
10	0.00×10^{-3}
12	0.01
14	0.03

T	$\Delta L/L_0$
CURVE 19 (cont.)*,†,‡	
16	0.07×10^{-3}
18	0.14
20	0.23
22	0.37
24	0.61
26	0.95
28	1.40
30	1.98
35	4.10
40	7.30
45	11.63
50	17.05
60	30.75
65	38.94
70	47.97
75	57.77
80	68.23
CURVE 20*,†,‡	
3.452	0.000×10^{-3}
3.682	0.000
3.985	0.000
4.435	0.000
4.936	0.000
5.586	0.001
6.106	0.001
6.644	0.002
7.182	0.003
7.832	0.004
8.524	0.006
9.229	0.009
9.990	0.013
10.748	0.017
11.472	0.023
12.463	0.033
13.736	0.051
14.983	0.077
16.322	0.115
17.824	0.176
19.512	0.274
21.443	0.377
23.345	0.545
25.099	0.823
26.875	1.186
28.870	1.703
65.000	37.833
75.000	56.583

T	$\Delta L/L_0$
CURVE 20 (cont.)*,†,‡	
85	78.233×10^{-3}
283	667.283
CURVE 21‡	
293	0.000
300	0.025
400	0.394
500	0.796
600	1.231
700	1.698
800	2.201
900	2.739
952	3.032
CURVE 22‡	
76	-0.661
95	-0.619
109	-0.585
123	-0.549
147	-0.482
173	-0.406
197	-0.331
220	-0.255
222	-0.248
293	0.000
297	0.015
329	0.133
370	0.289
425	0.504
476	0.712
521	0.904
548	1.022
572	1.132
CURVE 23*	
293	0.000
1034	4.64
CURVE 24	
293	0.00
473	0.68
573	1.05
673	1.41
716	1.60

T	$\Delta L/L_0$
CURVE 24 (cont.)	
821	2.11
924	2.71
973	2.94
1032	3.18
CURVE 25	
293	0.00
473	0.57
573	0.91
673	1.26
719	1.46
749	1.60
773	2.01
816	2.19
873	2.46
921	2.86
973	3.13
1023	4.13
CURVE 26*,‡	
140	-0.487
169	-0.405
178	-0.377
200	-0.308
209	-0.280
216	-0.258
229	-0.217
230	-0.214
257	-0.127
267	-0.093
291	-0.007
293	0.000
314	0.076
377	0.311
414	0.454
577	1.140
605	1.267
CURVE 27*	
293	0.00
593	1.25

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 275. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POTASSIUM CHLORIDE KCl

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
7	0.008*
8	0.018*
9	0.030*
10	0.052*
11	0.077*
12	0.113*
13	0.15*
14	0.19*
15	0.24*
16	0.30*
17	0.37*
18	0.45*
19	0.57
20	0.69*
22	1.02*
24	1.44*
26	1.93
28	2.49*
30	3.11
32	3.77*
34	4.53*
36	5.32
38	6.16*
40	7.08
45	9.25*
50	11.43
55	13.30
60	15.30
65	
70	18.80
80	21.55
90	23.68
100	25.42
125	28.58
150	30.80
175	32.54
200	33.52
250	35.42
290	36.80
CURVE 2‡	
223	37
233	37
253	37
273	36
293	36*
293	36*
313	36*
333	36*
353	37*
373	37*
393	37*
413	37*
433	37*
453	37*
473	37*
CURVE 4‡	
6	0.009*
7	0.016*
8	0.023*
10	0.055
12	0.10*
14	0.17*
16	0.30*
18	0.49*
20	0.74
22	1.07*
24	1.49
26	2.00*
28	2.56
30	3.22*
65	17.5
75	20.5
85	23.0
CURVE 5‡	
24	1.1
30	2.4
34	4.8
37	4.0
41	7.6
45	8.1
49	10.3
53	12.3
58	14.0
63	16.2
68	17.3*
68	18.3*
72	18.4
79	19.5*
84	20.5
86	22.3*
91	23.1
92	22.5*
96	23.8
100	24.1*
102	25.4
104	25.1*
106	27.0
107	26.4*
115	28.2
116	27.8*
125	28.7*
134	28.9
138	29.4
142	29.8*
144	30.1*
148	30.7*
156	31.4
158	30.8*
168	31.9*
176	32.7*
180	33.4
188	33.1*
192	33.1
198	33.1*
201	33.5*
206	34.2
216	33.8
226	34.8
229	35.1*
236	35.1
238	35.4*
246	35.1*
247	34.6
254	35.8
258	35.9*
263	35.9
272	36.4*
279	36.7
CURVE 12*,‡	
369.5	35.87
425.3	40.52
485.1	39.52
545.5	44.30
600.3	46.57
654.8	48.56
709.7	50.96
759.4	53.56
808.2	55.04
862.2	55.78
887.0	57.16
CURVE 13*,‡	
425.3	45.73
485.1	39.37
545.5	40.40
600.3	49.45
654.8	46.81
709.7	47.24
759.4	55.78
808.2	52.20
862.2	48.06
887.0	48.66
CURVE 15‡	
16.560	0.17
22.74	1.02*
28.80	2.86*
34.83	4.90*
41.32	7.74*
50.32	11.56
61.33	15.97
70.95	18.81*
78.95	21.31
83.050	22.23*
91.74	23.91
101.83	25.48*
111.62	27.02
120.99	28.13
132.00	29.12
144.157	30.33
157.83	31.36
172.68	32.22
187.91	32.87
202.70	33.61*
217.68	34.27
233.86	34.82
252.72	35.50
266.288	35.94
272.15	36.23*
286.77	36.76
288.51	36.82*
CURVE 16‡	
30	3.24*
40	6.61
87	23.5
104	27.5
CURVE 17‡	
109.0	22.0
131.8	25.9
150.7	29.3
163.7	30.6
181.2	32.6
197.6	33.5
212.2	34.2
243.0	34.5
273.2	35.2
288.2	35.9
329.5	38.0*
364.2	39.3*
396.8	40.2*
429.9	41.0*
461.7	42.6*
493.9	45.1*
523.1	46.4*
550.6	47.8*
CURVE 18*,‡	
293	37.1
324	38.1
376	39.5
474	42.9
573	46.0
674	49.0
773	52.4
823	54.0
873	55.9
923	59.1
946	60.9
971	63.7
996	66.3
1021	69.6
CURVE 19*,‡	
10	0.04
12	0.09
14	0.16
16	0.25
18	0.37
20	0.55
22	0.91
24	1.41
26	2.00
28	2.54
30	3.21
35	5.29
40	7.51
45	9.82
50	11.86
60	15.54
65	17.25
70	18.87
75	20.30
80	21.57
CURVE 20*,‡	
3.452	0.0022
3.682	0.0025
3.985	0.0034
4.435	0.0048
4.936	0.0068
5.586	0.0088
6.106	0.0118
6.644	0.0153
7.182	0.0201
7.832	0.0264
8.524	0.0338
9.229	0.0390
9.990	0.0546
10.748	0.0699
11.472	0.0862
12.463	0.1175
13.736	0.1717
14.983	0.2380
16.322	0.3344
17.824	0.4740
19.512	0.6826
21.443	0.3880
23.345	1.3790
25.099	1.7940

* Not shown in figure.

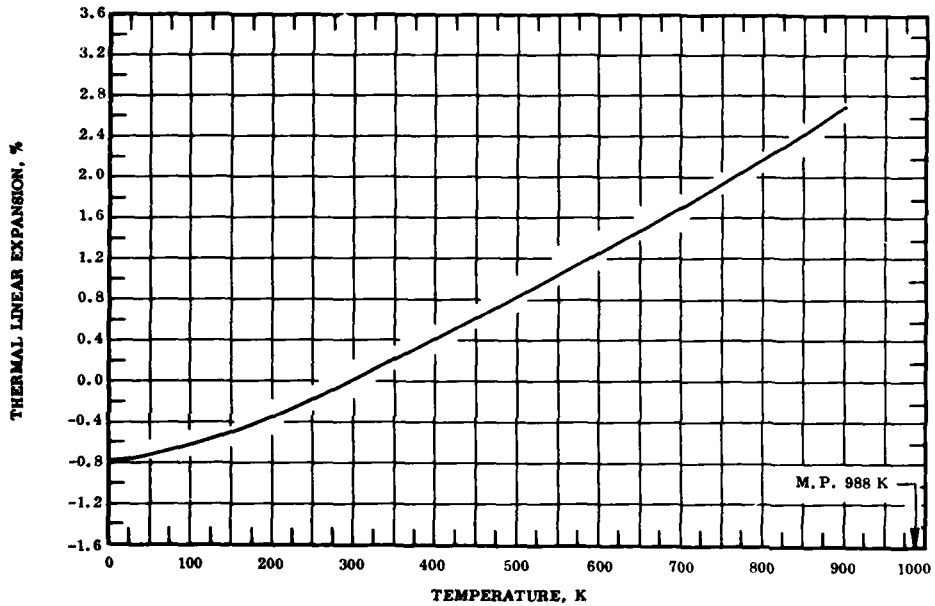
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 275. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POTASSIUM CHLORIDE KCl (continued)

T	α
CURVE 20 (cont.)*,‡	
26.875	2.2860
28.870	2.9000
65.000	17.1000
75.000	20.4000
85.000	22.9000
283.000	36.6000
CURVE 21*,‡	
293	35.0
300	35.3
400	38.6
500	41.8
600	45.1
700	48.4
800	52.1
900	55.5
952	57.4
CURVE 22*,‡	
76	20.4
95	23.6
109	25.1
123	27.0
147	28.1
173	30.4
197	32.1
220	34.7
222	33.4
293	36.4
297	36.8
329	37.4
370	38.3
425	40.0
476	41.6
521	43.8
548	43.8
572	47.3
CURVE 26*,‡	
140	25.9
169	30.4
178	31.0
200	31.8
209	31.8
216	31.4
229	30.7
230	31.6
257	33.2
267	34.7
291	36.4
293	36.4
314	36.4
377	38.1
414	39.3
577	44.8
605	46.1

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 276R. *RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF RUBIDIUM CHLORIDE* RbCl



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
2	-0.751	-0.0002
3	-0.751	-0.0007
5	-0.751	0.0001
10	-0.751	0.2
20	-0.750	1.2
25	-0.749	2.2
30	-0.749	3.2
40	-0.741	10.7
50	-0.729	15.0
75	-0.682	21.7
100	-0.622	25.8
150	-0.484	30.3
200	-0.326	33.0
250	-0.157	34.8
293	0.000	36.2
300	0.021	36.6
400	0.407	38.8
500	0.824	42.0
600	1.268	45.0
700	1.734	48.3
800	2.216	51.9
900	2.708	55.3

REMARKS

The recommended values agree well with most of the experimental data. These values are considered accurate to within ± 5% and are represented by the following equation:

$$\Delta L/L_0 = -0.886 + 2.292 \times 10^{-3}\, T + 2.709 \times 10^{-6}\, T^2 - 9.101 \times 10^{-10}\, T^3 \qquad (150\text{–}900\ K)$$

The tabulated values for the coefficient of thermal expansion are derived primarily from the selected experimental data and are considered accurate to about ± 7%.

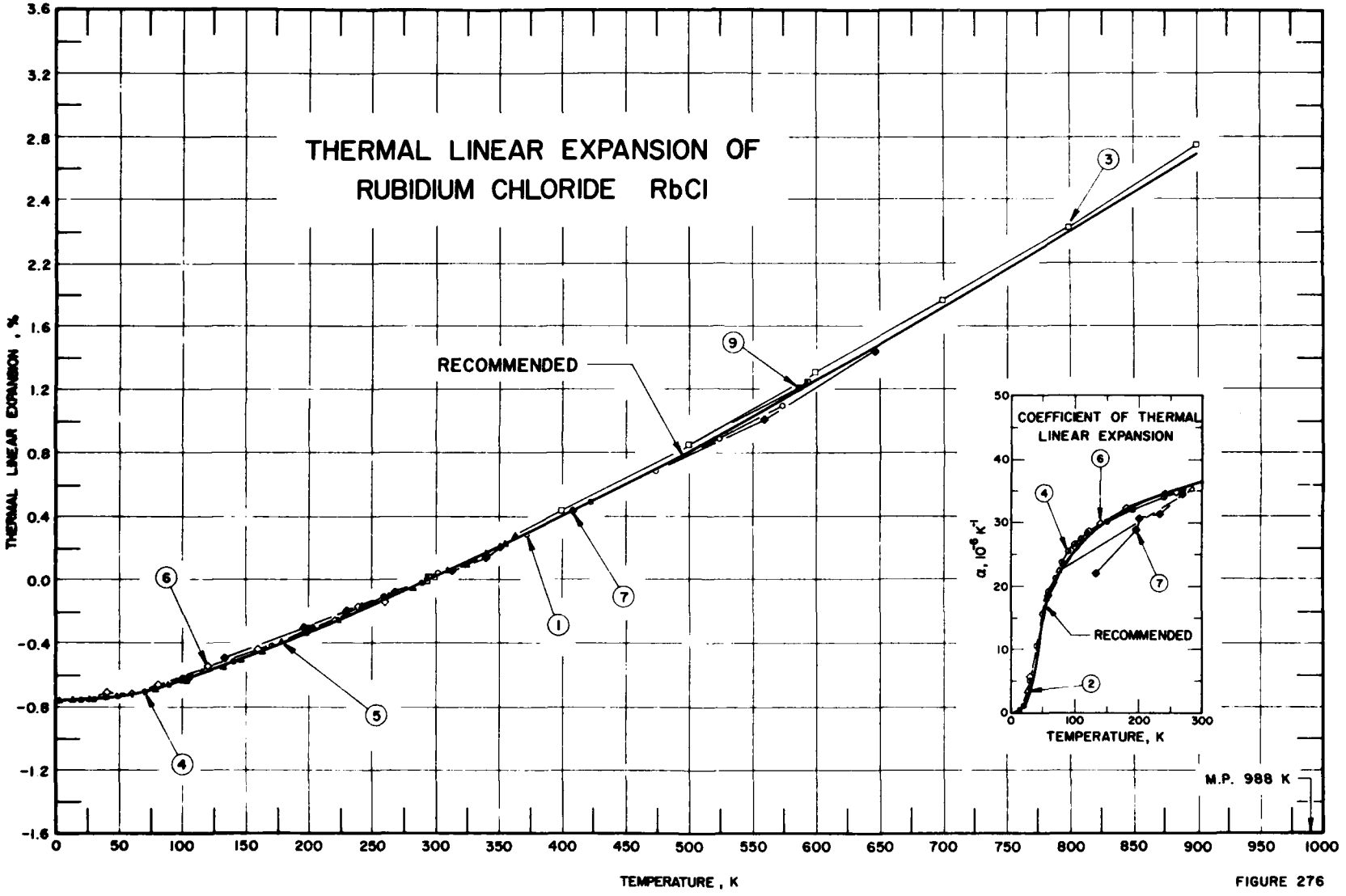

THERMAL LINEAR EXPANSION OF
RUBIDIUM CHLORIDE RbCl
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED
M.P. 988 K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
α, 10⁻⁶ K⁻¹
TEMPERATURE, K
RECOMMENDED

FIGURE 276

SPECIFICATION TABLE 276. THERMAL LINEAR EXPANSION OF RUBIDIUM CHLORIDE RbCl

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	481	McKinstry, H. A.	1960	X	301-573		Specimen prepared from a chemically pure $RbCO_3$ and chemically pure hydrochloric acid; 1% potassium and <1.1% bromine; reliable data; lattice parameter reported at 301 K as 6.5776 Å; 6.5756 Å at 293 K determined by graphical extrapolation.
2*	623	White, G. K. and Collins, J. G.	1973	E	2-283		Cylindrical specimen of 20 mm diameter x 50.8 mm long; obtained from Isomet Corp. of New Jersey; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
3	623	Srivastava, K. K. and Merchant, H. D.	1972	X	293-900		No details given.
4	761	Gloyas, M., Hugles, F. D., and James, B. W.	1970		20-300	Crystal No. 1	Total impurity <22 ppm; dimensions: 1 x 1 x 1.9765 cm; cleaved from a single large crystal along (100) cleavage plane; ends were ground and polished; density at 300 K was 2.8172 g/cm^3 which was calculated from the lattice spacing of 6.4810 Å; this value for the lattice spacing was obtained from the ASTM Powder Diffraction File and its molecular weight at 120.92 obtained from New Metals and Chemicals Ltd.; reported error 0.2%.
5	762	Urvas, O.	1971	X	4.7-368.1		Crystals grown in author's laboratory by the Kyropoulas method; salt was of the quality << Suprapur 7619>> manufactured by E. Merck AG, Darmstadt, W. Germany; below 70 K Co radiation and the (046) plane was used; above 70 K Cu radiation and the (064) plane was used; lattice parameter reported at 292 K as 6.5926 Å; 6.5873 Å at 273 K determined by graphical interpolation; smoothed data.
6	762	Cooper, R. F. and Yates, B.	1971	I	30-260		Smoothed data.
7	663	Von Trost, K. F.	1963		134-647		No details given.
8*	632	Bridgman, P. W.	1932		303,348		Dimension: cylindrical rod, 0.952 cm diameter x 0.952-1.27 cm long; lever piezometer method used to measure expansion.
9	664	Whittemore, P. O.	1962	L	293,593		Dimensions: cylindrical 1.27 cm diameter x 2.54 cm long specimen made by pressing reagent grade chemicals in a steel mold at 703 kg/cm; original length measured by micrometer 2.54 μm measurement made with two cylinders placed end to end.

* Not shown in figure.

DATA TABLE 276. THERMAL LINEAR EXPANSION OF RUBIDIUM CHLORIDE RbCl

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
301.20	0.030
372.45	0.295
423.45	0.487
473.45	0.687
524.45	0.894
573.45	1.110
CURVE 2*, †, ‡	
2.382	0.00000×10^{-2}
3.015	0.00000
3.775	0.00001
4.429	0.00001
4.845	0.00001
5.249	0.00001
5.649	0.00000
6.001	0.00000
6.391	0.00000
6.809	0.00001
7.273	0.00003
7.833	0.00006
8.492	0.0001
8.492	0.0001
9.199	0.0002
9.930	0.0006
9.930	0.0006
10.695	0.001
10.695	0.001
11.745	0.002
13.035	0.005
14.260	0.009
15.474	0.016
16.812	0.026
18.377	0.044
20.097	0.070
21.869	0.106
23.585	0.152
25.055	0.200
26.415	0.252
28.071	0.327
29.591	0.406
57.5	3.737
65.0	5.177
75.0	7.300
85.0	9.642
283.0	68.775

T	$\Delta L/L_0$
CURVE 3‡	
293	0.000
300	0.028
400	0.434
500	0.860
600	1.306
700	1.771
800	2.254
900	2.752
CURVE 4‡	
20	-0.752
30	-0.749
40	-0.742
50	-0.729*
60	-0.711*
70	-0.691
80	-0.668*
90	-0.643*
100	-0.617
110	-0.590*
120	-0.562*
130	-0.534*
140	-0.505
150	-0.475*
160	-0.444*
170	-0.413
180	-0.382*
190	-0.350*
200	-0.318
210	-0.285*
220	-0.252*
230	-0.219
240	-0.185*
250	-0.151*
260	-0.117
270	-0.082*
288	-0.046*
290	-0.011
300	0.025*
CURVE 5	
4.7	-0.759
5.1	-0.758*
6.1	-0.761*

T	$\Delta L/L_0$
CURVE 5 (cont.)	
7.8	-0.758*
13.9	-0.759
19.7	-0.761*
23.6	-0.760*
27.8	-0.757
33.6	-0.753*
38.3	-0.749*
44.4	-0.743*
49.1	-0.737
54.9	-0.729*
58.6	-0.720*
64.2	-0.710*
65.9	-0.704*
78.0	-0.682
78.3	-0.675*
82.9	-0.668*
87.9	-0.653
92.5	-0.645*
97.2	-0.630*
102.2	-0.620
107.2	-0.601*
112.2	-0.589*
117.2	-0.576
122.2	-0.561*
127.3	-0.547*
132.3	-0.531
137.2	-0.517*
142.2	-0.501*
146.8	-0.488
153.2	-0.468*
157.8	-0.454*
162.7	-0.440
167.8	-0.422*
173.0	-0.409*
173.0	-0.409*
178.1	-0.392
183.2	-0.378*
188.4	-0.359*
193.5	-0.341*
198.6	-0.324
203.7	-0.308
208.8	-0.292*
213.9	-0.275*
219.0	-0.257*
223.9	-0.241*
228.4	-0.226*

T	$\Delta L/L_0$
CURVE 5 (cont.)	
234.0	-0.207*
239.0	-0.190*
243.8	-0.171
248.6	-0.157*
253.6	-0.139*
258.5	-0.127*
263.5	-0.105
269.0	-0.087*
274.3	-0.064*
279.1	-0.049*
281.7	-0.047
286.5	-0.024*
290.7	-0.015*
292.1	-0.003*
296.0	0.008*
300.1	0.023*
300.2	0.022*
300.2	0.023*
304.6	0.038*
309.0	0.055
313.1	0.070*
317.3	0.084*
321.4	0.098*
325.5	0.114
329.5	0.128*
333.3	0.143*
337.2	0.158*
340.9	0.173
344.5	0.184*
348.1	0.200*
351.7	0.211*
355.0	0.224
358.7	0.238*
361.6	0.250*
364.8	0.262*
368.1	0.273
CURVE 6‡	
30	-0.749*
40	-0.741
50	-0.728*
60	-0.711
80	-0.669
100	-0.619*
120	-0.564

T	$\Delta L/L_0$
CURVE 6 (cont.)‡	
140	-0.506*
160	-0.445
180	-0.382*
200	-0.317*
220	-0.250
240	-0.183
260	-0.114
CURVE 7‡	
134	-0.476
198	-0.312
201	-0.304*
231	-0.211
268	-0.089
276	-0.061*
293	0.000*
311	0.066
341	0.178
351	0.215
408	0.435
408	0.435*
559	1.058
647	1.453
CURVE 8*	
303	0.121
348	0.665
CURVE 9	
293	0.00
593	1.25

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 276. COEFFICIENT OF THERMAL LINEAR EXPANSION OF RUBIDIUM CHLORIDE RbCl

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

CURVE 2*,‡

T	α
2.382	-0.0002
3.015	-0.0007
3.775	-0.0001
4.429	-0.0002
4.845	0.0001
5.249	0.0001
5.649	0.0018
6.001	0.0005
6.391	0.0014
6.809	0.0022
7.273	0.0046
7.833	0.0080
8.492	0.0141
8.492	0.0149
9.199	0.0298
9.930	0.0531
9.930	0.0523
10.695	0.0907
10.695	0.0908
11.745	0.1567
13.035	0.2828
14.260	0.4451
15.474	0.644
16.812	0.914
18.377	1.290
20.097	1.781
21.869	2.336
23.585	2.993
25.055	3.540
26.415	4.148
28.071	4.850
29.591	5.523
57.5	18.35
65.0	20.04
75.0	22.42
85.0	24.43
283.0	35.30

CURVE 3*,‡

T	α
293	39.3
300	39.7
400	41.5
500	43.7
600	45.6
700	47.4

CURVE 3 (cont.)*,‡

T	α
800	49.2
900	50.4

CURVE 4*,‡

T	α
20	1.1
30	5.0
40	10.4
50	15.6
60	19.2
70	21.9
80	23.9
90	25.4
100	26.6
110	27.5
120	28.2
130	28.9
140	29.5
150	30.1
160	30.8
170	31.1
180	31.5
190	32.0
200	32.4
210	32.8
220	33.2
230	33.6
240	34.0
250	34.4
260	34.7
270	35.1
280	35.4
290	35.8
300	36.1

CURVE 6‡

T	α
30	5.6
40	10.3*
50	15.2*
60	18.9
80	23.4*
100	26.3
120	28.4
140	29.9
160	31.1*

CURVE 6 (cont.)‡

T	α
180	32.1
200	32.9*
220	33.6*
240	34.2
260	34.7

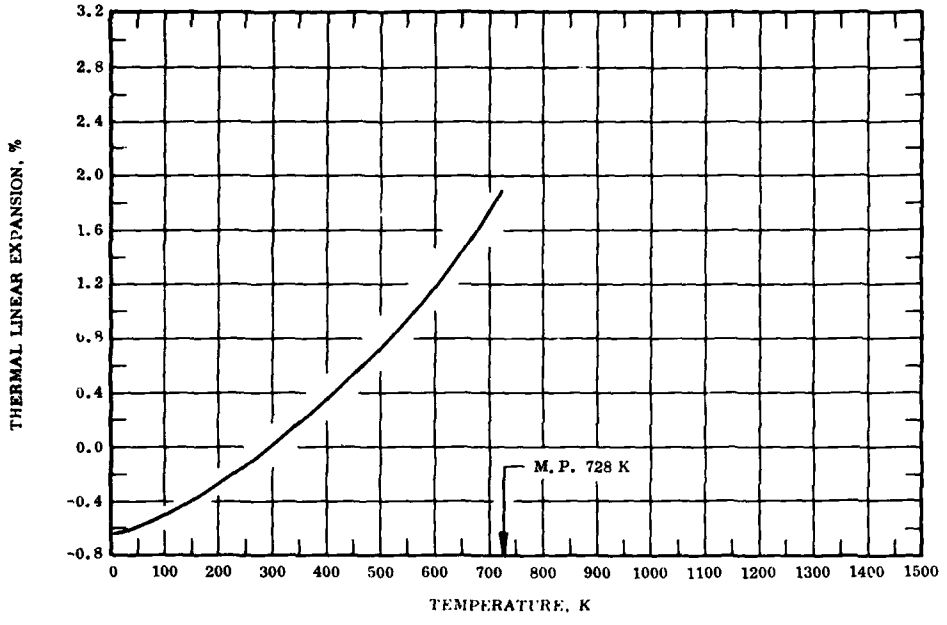
CURVE 7‡

T	α
134	22.0
198	29.0
201	30.4
231	31.3
268	34.5
276	35.6*
293	36.4*
311	37.0
341	37.3*
351	37.7*
408	39.5
408	38.9
559	43.6
647	46.1

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 277R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SILVER CHLORIDE AgCl



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
5	-0.633	0.5†
25	-0.628	6.0
50	-0.602	12.9
75	-0.567	16.6
100	-0.524	19.7
150	-0.417	24.5
200	-0.287	28.0
250	-0.138	30.5
293	0.000	32.1
300	0.023	32.4
350	0.187	33.9
400	0.356	35.0
450	0.535	36.9
500	0.729	40.0
550	0.943	44.5
600	1.183	50.4
650	1.455	58.3
700	1.762	69.1
725	1.931	75.6

† Extrapolated value.

REMARKS

The recommended values are based on the data for high-purity samples (curves *3* and *6*) and are considered accurate to within ± 5%. These values are represented approximately by the following equations:

$$\Delta L/L_0 = -0.645 + 4.699 \times 10^{-4}\, T + 8.149 \times 10^{-6}\, T^2 - 7.647 \times 10^{-9}\, T^3 \qquad (25\text{-}293\ K)$$

$$\Delta L/L_0 = -1.173 + 5.325 \times 10^{-3}\, T - 6.605 \times 10^{-6}\, T^2 + 7.125 \times 10^{-9}\, T^3 \qquad (293\text{-}725\ K)$$

The tabulated values for the coefficient of thermal expansion at temperatures above 100 K are derived from the selected experimental data. The values below 100 K are calculated primarily by differentiating the above equation. The tabulated values are considered accurate to about ± 7% at temperatures above 100 K and ± 10% below 100 K.

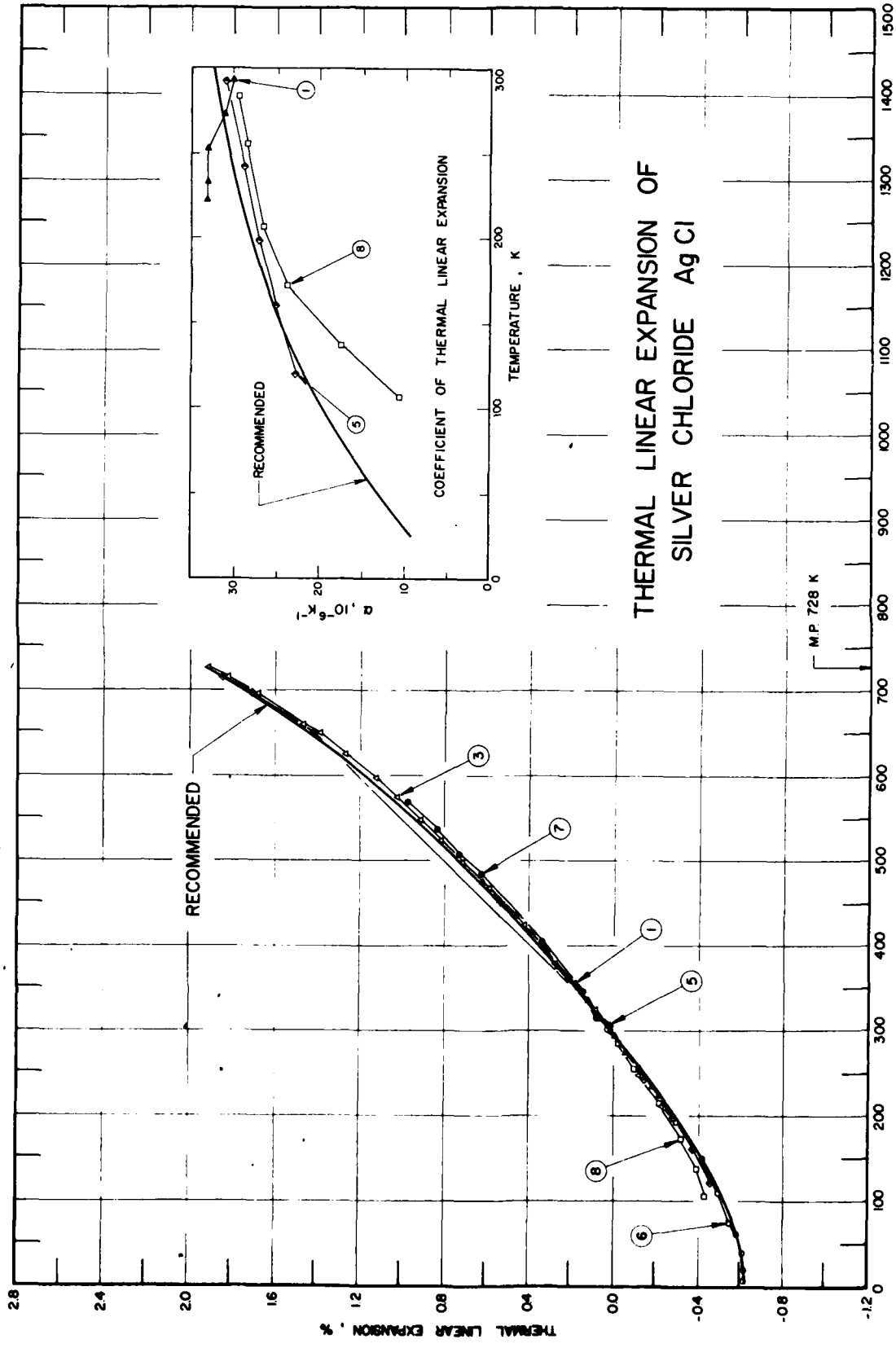

THERMAL LINEAR EXPANSION OF
SILVER CHLORIDE Ag Cl
M.P. 728 K
RECOMMENDED
COEFFICIENT OF THERMAL LINEAR EXPANSION
α, 10⁻⁶K⁻¹
TEMPERATURE, K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K

FIGURE 277

SPECIFICATION TABLE 277. THERMAL LINEAR EXPANSION OF SILVER CHLORIDE AgCl

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	322	Combes, L. S., Ballard, S. S., and McCarthy, K. A.	1951	L	223-473		Bar specimen furnished by Harshaw Chemical Co. of Cleveland, Ohio.
2*	322	Combes, L. S., et al.	1951	L	223-473		The above specimen; average values.
3	1031	Fouchaux, R. D.	1964	X	210-723		99.99+ pure; principal impurity 0.001 Al; sample extruded at 4×10^4 kg/cm^2, straightened in bakelite press, recrystallized on fused quartz 12 hr at 713 K, cooled slowly; grains extended across entire cross-section and 5 to 50 mm long; expansion measured on large grain with [110] crystallographic axis 3° from sample face normal; bar cut to 53 cm length with this grain in center; expansion measured using Fe $K\alpha_1$ x-radiation (λ = 1.93597 Å) and 2 min to over 2 hr exposure; data average (smoothed) of results on several thermal cycles.
4*	1031	Fouchaux, R. D.	1964	T	248-723		The above specimen; expansion measured with different technique.
5	763	Nicklow, R. M. and Young, R. A.	1963	X	120-713		Single crystal sample of ultrapure AgCl obtained from F. Moser of Eastman Kodak Co.
6	160	Schaake, H. F.	1969	X	4.2-300		Specimen precipitated from $AgNO_3$ with excess NaCl solution, washed with distilled water, dried, powdered to <325 mesh; 10% iridium added for calibration; pressed into copper sample holder; lattice parameter reported at 298.6 K as 5.5503 Å; 5.5494 Å at 293 K determined by graphical interpolation.
7	161	Sharma, S. S.	1950		315-598		Special melt-grown polycrystalline mass in form of uniform sheet.
8	764	Sreedhar, A. K.	1954		106-284		Crystalline in cubic system; specimen is part of a special melt-grown polycrystalline mass; the flattening of the α-T curve on either side of room temperature is, according to Sharma, S. S., suggestive of a change in the structure.

* Not shown in figure.

DATA TABLE 277. THERMAL LINEAR EXPANSION OF SILVER CHLORIDE AgCl

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1‡

T	$\Delta L/L_0$
223	-0.224
233	-0.191
253	-0.125
273	-0.061
293	0.000
313	0.060
333	0.121
353	0.184
373	0.250
393	0.319
413	0.390
433	0.462
453	0.536
473	0.614

CURVE 2*

T	$\Delta L/L_0$
223	-0.217
293	0.000
373	0.248
473	0.612

CURVE 3

T	$\Delta L/L_0$
210.7	-0.242
223.2	-0.207*
248.2	-0.135
273.2	-0.061
298.2	0.015
323.2	0.093
348.2	0.173
373.2	0.255*
379.1	0.275
398.2	0.340
421.5	0.421
423.2	0.426*
448.2	0.517
468.1	0.592
473.2	0.611*
498.2	0.709
522.3	0.805
523.2	0.809*
548.2	0.913
571.1	1.010
573.2	1.023*
598.2	1.139

CURVE 3 (cont.)

T	$\Delta L/L_0$
615.9	1.225*
623.2	1.262
648.2	1.396
658.2	1.454
673.2	1.546*
694.2	1.688
698.2	1.712*
713.2	1.826
717.1	1.858*
723.2	1.910

CURVE 4*

T	$\Delta L/L_0$
248.2	-0.135
273.2	-0.061
298.2	0.015
323.2	0.093
348.2	0.173
373.2	0.256
379.1	0.276
398.2	0.341
421.5	0.422
423.2	0.427
448.2	0.518
468.1	0.592
473.2	0.611
498.2	0.709
522.3	0.805
523.2	0.809
548.2	0.913
571.1	1.009
573.2	1.022
598.2	1.138
615.9	1.223
623.2	1.259
648.2	1.392
658.0	1.450
673.2	1.542
694.7	1.684
698.2	1.708
713.2	1.822
717.1	1.854
723.2	1.906

CURVE 5‡

T	$\Delta L/L_0$
120	-0.470
160	-0.374
199	-0.272
241	-0.155
293	0.000
302	0.027
352	0.187
499	0.720
598	1.154
648	1.412
698	1.734
713	1.850

CURVE 6

T	$\Delta L/L_0$
4.2	-0.628
20	-0.628
40	-0.620
60	-0.593
77.4	-0.564
110.5	-0.503
150	-0.415
194.5	-0.289
240	-0.150*
298.6	0.0158*
300	0.0166*

CURVE 7‡

T	$\Delta L/L_0$
315.7	0.070
345.5	0.163
375.0	0.257*
403.8	0.349
431.6	0.441*
458.1	0.534*
483.4	0.626
507.6	0.718
536.0	0.832
568.2	0.970
598.2	1.108*

CURVE 8‡

T	$\Delta L/L_0$
106.2	-0.442
137.2	-0.399
172.7	-0.326

CURVE 8 (cont.)‡

T	$\Delta L/L_0$
213.4	-0.223
255.2	-0.109
284.7	-0.024

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 277. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SILVER CHLORIDE AgCl

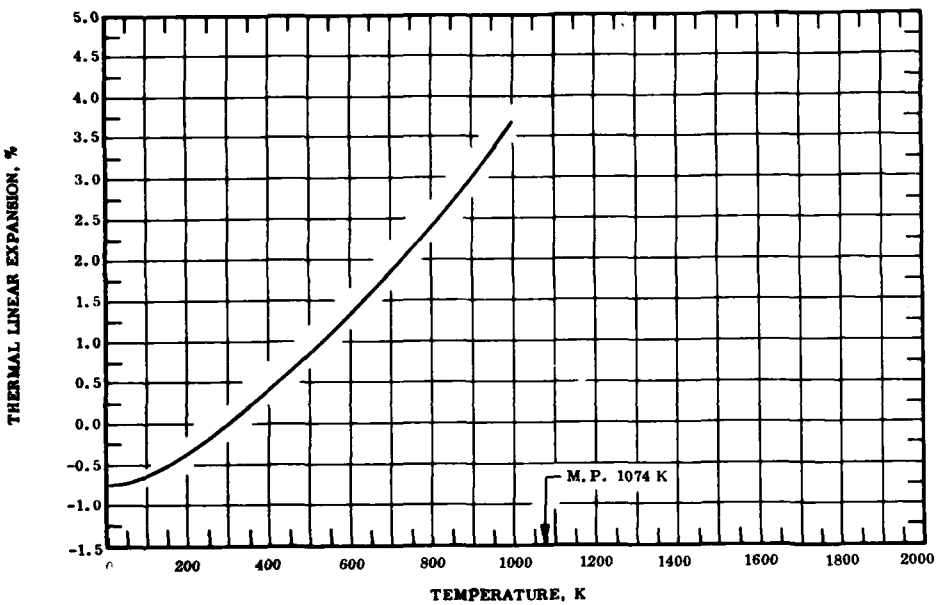
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
223	33
233	33
253	33
273	31
293	30*
313	30
333	31
353	32
373	34
393	35
413	36
433	36
453	38
473	40
CURVE 5‡	
120	22.8
160	25.1
199	27.0
241	28.8
293	31.0
302	31.0
352	32.3
499	40.3
598	47.3
648	56.1
698	72.5
713	82.3
CURVE 7*,‡	
315.7	31.05
345.5	31.45
375.0	31.66
403.8	32.58
431.6	33.94
458.1	35.73
483.4	37.11
507.6	38.95
536.0	41.49
568.2	44.10
598.2	47.74

T	α
CURVE 8‡	
106.2	10.5
137.2	17.3
172.7	23.9
213.4	26.5
255.2	28.2
284.7	29.5

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 278R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SODIUM CHLORIDE NaCl



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
5	-0.772	0.007
10	-0.772	0.06
15	-0.772	0.22
20	-0.771	0.56
25	-0.771	1.20
50	-0.759	9.6
75	-0.722	19.0
100	-0.666	25.3
150	-0.521	31.7
200	-0.352	35.4
250	-0.168	38.2
293	0.000	40.0
400	0.448	43.5
500	0.896	45.9
600	1.371	49.0
700	1.878	52.7
800	2.430	57.7
900	3.034	63.5
1000	3.699	69.5

REMARKS

The recommended values are based on the data for high-purity samples and are considered accurate to within ± 5%. These values are represented approximately by the following equations:

$$\Delta L/L_0 = -1.064 + 3.205 \times 10^{-3}\ T + 1.471 \times 10^{-6}\ T^2 - 8.559 \times 10^{-11}\ T^3 \qquad (293\text{-}600\ K)$$

$$\Delta L/L_0 = -1.161 + 4.030 \times 10^{-3}\ T - 4.554 \times 10^{-7}\ T^2 + 1.285 \times 10^{-9}\ T^3 \qquad (600\text{-}1000\ K)$$

The tabulated values for the coefficient of thermal expansion are derived primarily from the selected experimental data and are considered accurate to about ± 7%.

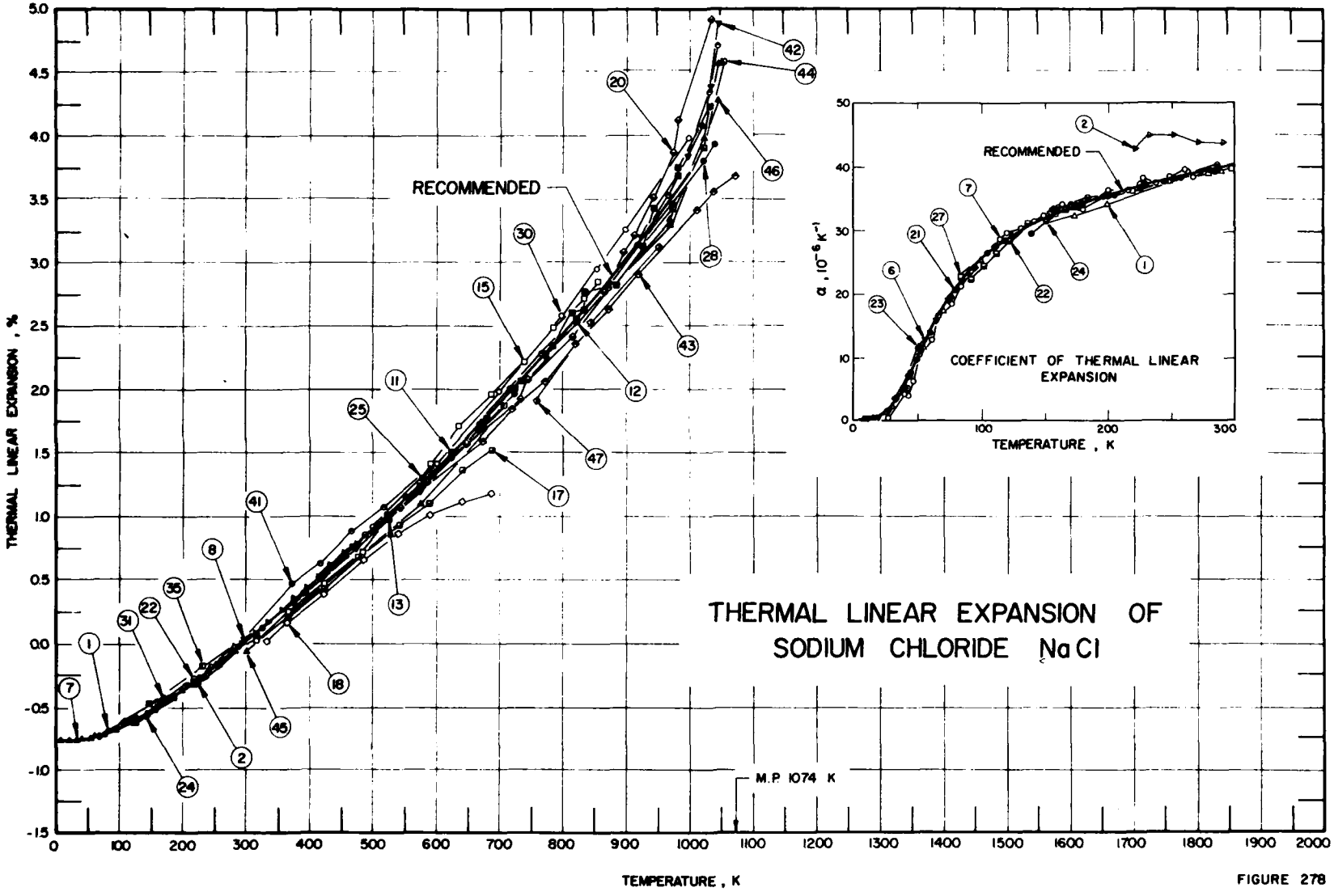

THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED
M.P. 1074 K
THERMAL LINEAR EXPANSION OF
SODIUM CHLORIDE NaCl
α , 10^{-6} K^{-1}
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
TEMPERATURE , K

FIGURE 278

SPECIFICATION TABLE 278. THERMAL LINEAR EXPANSION OF SODIUM CHLORIDE NaCl

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	478	Meincke, P. P. M. and Graham, G. M.	1965	I	7-290		Cylindrical specimen; 1.27 cm diameter x 5.4 cm long with an axial hole of 1.91 cm diameter; crystal supplied by the Harshaw Chemical Co.; smoothed data reported; reported error < 5%.
2	322	Combes, L. S., Ballard, S. S., and McCarthy, K. A.	1951	L	223-473		Bar specimen furnished by the Harshaw Chemical Co. of Cleveland, Ohio.
3*	322	Combes, L. S., *et al.*	1951	L	223-473		The above specimen; average values of expansion reported.
4*	765	Enck, F. D. and Dommel, J. G.	1965	D	323-1038		Single crystal specimen milled to 1 cm square with three parallel legs 0.5 cm long; reported error < 2%.
5*	766	Antoniou, A. A. and Litvan, G. G.	1967	O	260,280		Single crystal specimen.
6*	479	White, G. K.	1965	C	6-283		Specimen grown from melt of reagent grade material; specimen cylinder 2.0 cm diameter, 5 cm long; data smoothed by author; reported error 1.0%.
7	480	Yates, B. and Panter, C. H.	1962	I	24-280		Single crystal specimen obtained from Hilger and Watts Ltd. of London; grown from material 99.97 pure; expansion observed with cadmium green light (5085.8 Å).
8	481	McKinstry, H. A.	1960	X	296-772		Freshly cleaved surface of single crystal specimen; obtained from Harshaw Co.; the lattice parameter extrapolated to reduce systematic errors; the four orders of reflection for CuKβ were used; lattice parameter reported at 296.95 K as 5.63969 Å; 5.63879 Å at 293.2 K determined by graphical extrapolation.
9*	481	McKinstry, H. A.	1960	X	297-673		The above specimen; another run; lattice parameter reported at 297.95 K as 5.64026 Å; 5.63913 Å at 293 K determined by graphical extrapolation.
10*	481	McKinstry, H. A.	1960	X	297-675		The above specimen; second run; lattice parameter reported at 297.45 K as 5.64072 Å; 5.63976 Å at 293 K determined by graphical extrapolation.
11	481	McKinstry, H. A.	1960	X	294-823		The above specimen; only the high and low orders of reflection with CuKβ were used; third run; lattice parameter reported at 294.80 K as 5.6386 Å; 5.6382 Å at 293 K determined by graphical extrapolation.
12	481	McKinstry, H. A.	1960	X	298-873		The above specimen; another run; lattice parameter reported at 298.2 K as 5.63995 Å; 5.6388 Å at 293 K determined by graphical extrapolation.
13	481	McKinstry, H. A.	1960	X	292-724		The above specimen; another run; lattice parameter reported at 292.45 K as 5.63856 Å; 5.8387 Å at 293 K calculated by graphical extrapolation.
14*	481	McKinstry, H. A.	1960	X	298-773		Powder sample from the single crystal of NaCl from Harshaw Co.; sample support centered; the lattice parameter extrapolated to reduce systematic errors; lattice parameter reported at 298.2 K as 5.6402 Å; 5.6391 Å at 293 K determined by graphical extrapolation.
15	481	McKinstry, H. A.	1960	O	294-859		Single crystal of NaCl from Harshaw Co.; the average coefficient of thermal expansion from the previous temperature to the one in question.
16*	481	McKinstry, H. A.	1960	I	294-859		The above specimen.
17	481	McKinstry, H. A.	1960	O	300-689		The above specimen; another run.
18	481	McKinstry, H. A.	1960	I	300-689		The above specimen; another run.

* Not shown in figure.

SPECIFICATION TABLE 278. THERMAL LINEAR EXPANSION OF SODIUM CHLORIDE NaCl (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
19*	295	Hsu, Y.T.	1967	L	295-778		Reagent grade powder of cubic crystal in 0.3 mm diameter capillary; expansion measured along a-axis; lattice parameter reported at 295.5 K as 5.642 Å; 5.641 Å at 293 K determined by graphical interpolation.
20	767	Laredo, E.	1969	X	325-1036		Monocrystalline lamina 1 mm thick with a cross-sectional area of 1 cm^2; cleaved from a 20 cm^3 single crystal prepared from spectroscopically pure Johnson and Matthey NaCl in the laboratory by the method of fusion with temperature gradient; MoKα radiation used; zero-point correction of 0.147% determined by graphical extrapolation.
21*	768	Meincke, P.P.M. and Graham, G.M.	1963		10-285		Single crystal of salt, 2.5 cm O.D., 1.8 cm I.D. and 5 cm long; measured the change in length using the Fabry-Perot elalon technique; reported error 1-5%.
22	769	Rubin, T., Johnston, H.L., and Altman, H.W.	1961	I	92-279	Natural rock salt	Natural rock salt was obtained from Cincinnati Chemical Co.; the sample of material was cut into pillars adjusted to the length by careful filing; length of specimen at 25° was 1.113 cm.
23*	769	Rubin, T., et al.	1961	I	19-289	Synthetic rock salt	Synthetic rock salt obtained from the Harshaw Chemical Co.; material cut into pillars adjusted to the same length by careful filing; 0.5570 cm at 298 K.
24	756	Srinivasan, R.	1955		140-550		Pure sodium chloride.
25	770	Fischmeister, H.F.	1956	X	293-1034		Commercial preparation of NaCl (Merck, P.A.) used; zero-point correction is -0.1% at 293 K.
26	770	Fischmeister, H.F.	1956	X	293-1059		Similar to the above specimen; zero-point correction is -0.1% at 293 K.
27*	159	Buffington, R.M. and Latimer, W.M.	1926	I	85-310		Specimen cut from sample of rock salt.
28	621	Pathak, P.D. and Vasavada, N.G.	1970	X	293-1040		Powder specimen.
29*	623	White, G.K. and Collins, J.G.	1973	E	2-283		Dimensions: cylindrical specimen 20 mm diameter x 50.8 mm long; grown by Mr. J. S. Cook from reagent grade material containing a few ppm of hydroxyl ions and divalent cations; this curve is here reported using 2.735 K as the reference temperature at which $\Delta L/L_0 = 0$.
30	625	Srivastava, K.K. and Merchant, H.D.	1972	X	293-1003		No details given.
31	771	Rapp, J.E. and Merchant, H.D.	1972	L	67-576		Crystal orientation was <1,0,0>; dimensions 5 x 5 x 50 mm; smoothed data.
32*	772	Case, C.R., Swenson, C.R., and Swenson, H.	1973	L	3-30	OH-free	Dimensions: rectangular bar 0.06-3 cm x 0.06-1 cm x 10 cm long; obtained from R.O. Pohl (Cornell University); had rounded edges; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
33*	772	Case, C.R., et al.	1973	L	2-30		Similar to the above specimen except 0.000665 OH^{-1}; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
34*	772	Case, C.R., et al.	1973	L	2-29		Similar to the above specimen except heavily doped with 80 ppm OH; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

SPECIFICATION TABLE 278. THERMAL LINEAR EXPANSION OF SODIUM CHLORIDE NaCl (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
35	663	Von Trost, K. F.	1963		145-707		No details given.
36*	758	Case, C.R., McLean, K.O., and Swenson, C.A.	1972		3-28		This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
37*	758	Case, C.R., et al.	1972		4-24		Specimen with 130 ppm CN; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
38*	758	Case, C.R., et al.	1972		3-29		Pure sample; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
39*	758	Case, C.R., et al.	1972		5-23		Specimen with 500 ppm CN ; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
40*	664	Whittemore, P.O.	1962	L	293, 593		Cylindrical specimen of 1.27 cm diameter x 2.54 cm long; specimen formed by pressing reagent grade chemicals in a steel mold at 703 kg-cm^{-2}; original length measured by micrometer to 2.54 μm; measurement taken with two cylinders placed end to end.
41	773	Smirnov, M.V., Vasilevskaya, M.M., and Burov, G.V.	1970	X	293-1049		Specimen was tempered at 1008-1013 K; zero-point correction is 0.09% at 293 K.
42	773	Smirnov, M.V., et al.	1970		293-1049		The above specimen; pyconmetric method was used to measure expansion; zero-point correction is 0.09% at 293 K.
43	773	Smirnov, M.V., et al.	1970	L	273-1073		Same as the above specimen except zero-point correction is -0.1% at 293 K.
44	773	Smirnov, M.V., et al.	1970		293-1057		Same as the above specimen except used the pyconmetric method to measure expansion; zero-point correction is 0.01% at 293 K.
45	773	Smirnov, M.V., et al.	1970		293-1049		Spectrographic pure specimen; lattice parameter reported at 293 K as 5.629 Å.
46	773	Smirnov, M.V., et al.	1970		293-1047		Chemically pure specimen; lattice parameter reported at 293 K as 5.629 Å.
47	773	Smirnov, M.V., et al.	1970		293-953		Same as the above specimen except lattice parameter reported at 293 K as 5.634 Å.
48*	773	Smirnov, M.V., et al.	1970		293-1032		Single crystal; lattice parameter reported at 293 K as 5.629 Å.

* Not shown in figure.

DATA TABLE 278. THERMAL LINEAR EXPANSION OF SODIUM CHLORIDE NaCl

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
7	-0.756*
8	-0.756*
9	-0.756*
10	-0.756*
11	-0.756*
12	-0.756*
13	-0.756*
14	-0.756*
15	-0.756*
16	-0.756*
17	-0.756*
18	-0.756*
19	-0.756*
20	-0.756
22	-0.756*
24	-0.755*
26	-0.755*
28	-0.755*
30	-0.754*
32	-0.754*
34	-0.753*
36	-0.752*
38	-0.751*
40	-0.750
45	-0.747*
50	-0.743*
55	-0.737*
60	-0.731
65	-0.723*
70	-0.715*
80	-0.696
90	-0.674*
100	-0.651
125	-0.584
175	-0.430
200	-0.347
250	-0.166
290	-0.011
CURVE 2‡	
223	-0.311
233	-0.267
253	-0.177
273	-0.088
293	0.000
313	0.088
333	0.176
353	0.264
373	0.352
393	0.440
413	0.528
433	0.616
453	0.704
473	0.792
CURVE 3*	
223	-0.308
293	0.000
373	0.352
473	0.792
CURVE 4*	
323	0.123
373	0.328
423	0.540
473	0.760
523	0.988
573	1.225
623	1.472
673	1.729
698	1.861
723	1.995
773	2.273
823	2.559
873	2.855
923	3.165
938	3.262
973	3.495
988	3.597
1023	3.842
1028	3.878
1038	3.950
CURVE 5*	
260	-0.05
280	0.03
CURVE 6‡	
6	-0.780
7	-0.780
8	-0.780
10	-0.780
12	-0.780
14	-0.780
16	-0.780
18	-0.780
20	-0.780
22	-0.780
24	-0.780
26	-0.779
28	-0.779
30	-0.779
57.5	-0.757
65	-0.747
75	-0.729
85	-0.709
283	-0.040
CURVE 7‡	
24	-0.769*
27	-0.769*
31	-0.769
33	-0.768*
37	-0.767*
40	-0.766*
41	-0.766*
42	-0.766*
43	-0.765*
48	-0.763*
49	-0.762*
53	-0.758
55	-0.756*
57	-0.754*
61	-0.749*
67	-0.740*
67	-0.740*
69	-0.737
74	-0.729
76	-0.725*
80	-0.717*
85	-0.707*
93	-0.689
105	-0.658*
115	-0.631
122	-0.610*
132	-0.580*
134	-0.574*
141	-0.552
145	-0.539*
165	-0.473
167	-0.466*
173	-0.446*
177	-0.433*
183	-0.412*
187	-0.399*
199	-0.357
203	-0.342*
211	-0.313
217	-0.291*
226	-0.258*
228	-0.250*
238	-0.212
242	-0.197*
250	-0.167*
257	-0.140
264	-0.113*
268	-0.097*
280	-0.050
CURVE 8	
296.95	0.016
373.20	0.320
473.70	0.750
573.20	1.20
673.20	1.72
772.95	2.24
CURVE 9*	
297.95	0.020
466.45	0.712
472.70	0.742
572.45	1.200
673.45	1.700
CURVE 10*	
297.45	0.017
300.70	0.029
372.95	0.319
474.20	0.776
569.70	1.19
673.95	1.72
675.20	1.71
CURVE 11	
294.80	0.008*
373.45	0.342*
472.95	0.779*
523.20	1.01
572.95	1.24
622.95	1.50
672.95	1.74
722.45	2.00
773.20	2.28
823.45	2.56
CURVE 12	
298.2	0.022*
472.7	0.758*
673.7	1.72*
773.2	2.25*
822.4	2.54
873.2	2.84
CURVE 13	
292.45	0.000*
327.40	0.131
393.70	0.402
419.95	0.513*
475.95	0.760*
527.20	0.997
572.70	1.21*
622.95	1.46
666.70	1.68
724.45	1.98
CURVE 14*	
298.2	0.022
301.45	0.035
303.70	0.042
326.45	0.127
373.20	0.323
471.70	0.754
572.70	0.988
577.20	1.25
624.20	1.48
675.45	1.74
724.00	1.99
773.20	2.27
CURVE 15	
294.25	0.002*
317.50	0.045
369.93	0.250
427.97	0.485
483.93	0.719
590.77	1.415
636.44	1.722
688.64	1.976
740.04	2.236
789.50	2.494
834.71	2.731
859.23	2.856
CURVE 16*	
294.25	0.00210
317.50	0.0413
369.93	0.2353
427.97	0.4645
483.93	0.6920
590.77	1.3842
636.44	1.6930
688.64	1.9499
740.04	2.2137
789.50	2.4786
834.71	2.7211
859.23	2.9043
CURVE 17	
300.2	0.0117*
313.6	0.0335*
362.3	0.2028

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 278. THERMAL LINEAR EXPANSION OF SODIUM CHLORIDE NaCl (continued)

T	$\Delta L/L_0$
CURVE 17 (cont.)	
417.1	0.4187
422.4	0.4418
477.9	0.6949
484.6	0.7201
534.8	0.9170*
541.9	0.9410
590.3	1.1064
640.1	1.3745
689.9	1.5199
CURVE 18‡	
300.2	0.0074*
313.6	0.0211
362.3	0.1590
417.1	0.3769*
422.4	0.3992
477.9	0.6371*
484.6	0.6627
534.8	0.8610*
541.9	0.8872
590.3	1.0137
640.1	1.1365
689.9	1.1970
CURVE 19*	
295.5	0.018
309.5	0.089
330	0.195
347.5	0.248
374.5	0.390
406	0.567
435	0.674
457.5	0.780
471	0.833
489.5	0.904
518.5	1.046
555	1.170
583	1.294
603	1.383
623	1.454
646	1.649
668	1.720
692	1.826
713.5	1.932
738.5	2.021
765	2.251
778.5	2.340

T	$\Delta L/L_0$
CURVE 20	
325	0.071*
378	0.315*
429	0.551
541	1.074
588	1.284
646	1.580
735	1.938
748	2.086
818	2.418
869	2.784
899	3.081
913	3.221
943	3.517
968	3.866*
977	3.877
987	4.146
1036	4.931
CURVE 21*,‡	
10	-0.772
12	-0.772
14	-0.772
16	-0.772
18	-0.772
20	-0.772
22	-0.772
24	-0.772
26	-0.771
28	-0.771
30	-0.771
32	-0.770
34	-0.769
36	-0.769
38	-0.768
40	-0.767
45	-0.763
50	-0.759
55	-0.753
60	-0.747
65	-0.740
70	-0.731
80	-0.713
90	-0.691
100	-0.666
125	-0.598
150	-0.521
174.2	-0.441
245.4	-0.185

T	$\Delta L/L_0$
CURVE 21 (cont.)*,‡	
259.1	-0.132
285.55	-0.030
CURVE 22	
92.30	-0.680*
102.36	-0.657*
111.35	-0.634*
111.59	-0.633*
122.88	-0.602
137.86	-0.558*
152.42	-0.512
152.69	-0.511*
167.21	-0.464*
182.40	-0.412
178.15	-0.427*
199.95	-0.351*
218.38	-0.285
239.51	-0.207*
259.71	-0.130*
279.65	-0.053*
CURVE 23*,‡	
19.84	-0.773
26.473	-0.772
27.49	-0.772
29.05	-0.772
34.71	-0.770
36.41	-0.770
44.86	-0.765
52.74	-0.757
61.13	-0.747
69.56	-0.734
77.37	-0.720
74.83	-0.724
84.342	-0.705
86.80	-0.700
95.57	-0.679
97.81	-0.674
111.88	-0.637
126.35	-0.596
141.72	-0.550
159.97	-0.491
180.12	-0.422
202.80	-0.343
230.21	-0.242
259.95	-0.130
289.73	-0.014

T	$\Delta L/L_0$
CURVE 24‡	
140	-0.557
152	-0.520*
163.4	-0.483*
185.2	-0.408*
206.0	-0.334
226.7	-0.259
246.4	-0.185
263.9	-0.117
287.1	-0.025
315.2	0.089*
353.2	0.244*
390.2	0.400
425.2	0.554
456.2	0.696
489.2	0.851
521.2	1.007*
550	1.151
CURVE 25	
293	0.00*
375	0.35*
467	0.77
579	1.30
680	1.78
733	2.08
785	2.34
818	2.60
835	2.62
835	2.76
885	2.83
927	3.13
941	3.43
981	3.69
982	3.75
1034	4.23
CURVE 26*	
293	0.00
785	2.40
873	2.86
1014	3.90
1049	4.23
1059	4.33

T	$\Delta L/L_0$
CURVE 27*,‡	
85	-0.702
100	-0.666
120	-0.612
140	-0.553
160	-0.489
180	-0.421
200	-0.351
220	-0.279
240	-0.205
260	-0.130
280	-0.052
300	0.027
310	0.067
CURVE 28‡	
293	0.000*
326	0.133*
375	0.339*
475	0.781*
574	1.246*
675	1.754*
774	2.287*
823	2.563*
873	2.854*
921	3.145*
971	3.464
1021	3.805
1040	3.941
CURVE 29*,†,‡	
2.735	0.00000×10^{-2}
3.775	0.00003
4.489	0.00006
5.065	0.00010
5.194	0.00011
5.748	0.00016
5.909	0.00018
6.491	0.00026
6.544	0.00027
7.211	0.00040
7.884	0.00057
8.661	0.00083
9.458	0.00119
10.073	0.00153
10.627	0.00190
11.155	0.00232
11.737	0.00285

T	$\Delta L/L_0$
CURVE 29 (cont.)*,†,‡	
12.400	0.00358×10^{-2}
13.086	0.00448
13.816	0.00563
14.656	0.00722
15.642	0.00953
16.713	0.01268
17.853	0.01687
19.102	0.02266
20.458	0.03064
21.820	0.04075
23.039	0.05190
24.210	0.06475
25.446	0.08084
26.768	0.10130
28.262	0.12895
29.901	0.16531
58.000	2.31742
65.000	3.31282
75.000	5.03482
85.000	7.07032
283.000	67.37121
CURVE 30‡	
293	0.000*
300	0.027*
400	0.441*
500	0.904
600	1.418
700	1.982
800	2.596
900	3.256
1003	3.982
CURVE 31‡	
67	-0.728
78	-0.704*
94	-0.665*
108	-0.628
118	-0.601*
146	-0.519*
169	-0.446
196	-0.356*
229	-0.239*
273	-0.077*
293	0.000*
300	0.027*
324	0.121*

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 278. THERMAL LINEAR EXPANSION OF SODIUM CHLORIDE NaCl (continued)

T	$\Delta L/L_0$
CURVE 31 (cont.)‡	
374	0.321*
424	0.528*
474	0.743*
523	0.966*
550	1.096*
576	1.227
CURVE 32*,†,‡	
3.000	0.000 x 10^{-4}
3.250	0.000
3.750	0.002
4.375	0.004
4.875	0.007
5.500	0.012
6.500	0.025
7.000	0.034
7.500	0.046
8.500	0.076
9.500	0.121
10.500	0.182
11.500	0.265
12.500	0.375
13.000	0.441
14.500	0.699
16.001	1.065
18.000	1.774
20.000	2.861
22.000	4.383
24.000	6.405
26.000	9.097
28.000	12.584
30.000	17.005
CURVE 33*,†,‡	
2.70	0.000 x 10^{-4}
3.00	0.001
3.40	0.001
3.75	0.002
4.15	0.004
4.45	0.006
4.50	0.006
4.50	0.006
4.80	0.008
5.20	0.011
6.00	0.020
7.00	0.037

T	$\Delta L/L_0$
CURVE 33 (cont.)*,†,‡	
8.00	0.063 x 10^{-4}
9.00	0.101
10.50	0.188
11.50	0.272
13.00	0.451
15.00	0.822
20.00	2.943
25.00	7.861
30.00	17.431
CURVE 34*,†,‡	
2.225	0.000 x 10^{-4}
2.625	0.003
3.125	0.007
3.750	0.012
4.500	0.020
5.000	0.027
5.500	0.035
6.000	0.043
6.500	0.054
7.000	0.066
8.000	0.098
8.500	0.117
9.000	0.140
10.000	0.198
11.200	0.293
12.300	0.411
13.400	0.566
15.500	1.006
19.500	2.660
24.700	7.498
29.900	17.219
CURVE 35‡	
145	-0.489
156	-0.458*
180	385*
207	0.300*
231	-0.222*
262	-0.117*
267	-0.100*
275	-0.070*
280	-0.051*
293	0.000
300	0.028*
317	0.098*

T	$\Delta L/L_0$
CURVE 35 (cont.)‡	
408	0.487*
457	0.704*
489	0.848*
513	0.957*
595	1.342
625	1.485*
707	1.885
CURVE 36*,†,‡	
3.9	0.000 x 10^{-4}
4.3	0.002
5.2	0.008
5.2	0.008
5.8	0.013
6.5	0.023
7.2	0.037
7.8	0.052
8.7	0.082
9.6	0.123
10.3	0.165
11.2	0.232
11.6	0.269
12.5	0.367
13.1	0.446
13.6	0.523
14.7	0.728
15.6	0.939
17.9	1.709
19.1	2.267
20.4	3.028
21.9	4.147
24.3	6.598
25.7	8.467
26.8	10.201
28.4	13.195
CURVE 37*,†,‡	
4.0	0.000 x 10^{-4}
4.5	0.001
4.9	0.002
5.2	0.003
5.6	0.007
5.9	0.009
6.3	0.014
6.7	0.020
7.2	0.030

T	$\Delta L/L_0$
CURVE 37 (cont.)*,†,‡	
7.8	0.044 x 10^{-4}
8.4	0.063
9.2	0.095
9.9	0.131
10.7	0.184
11.8	0.279
12.9	0.406
13.9	0.560
15.1	0.806
16.5	1.188
18.2	1.832
19.6	2.544
21.2	3.611
23.0	5.190
24.9	7.384
CURVE 38*,†,‡	
3.2	0.000 x 10^{-4}
3.3	0.000
3.9	0.002
4.4	0.004
4.8	0.006
5.6	0.013
6.6	0.026
7.0	0.034
7.6	0.048
8.7	0.083
9.4	0.117
10.6	0.194
11.5	0.270
11.6	0.280
12.4	0.367
13.0	0.445
14.5	0.703
16.0	1.068
18.0	1.777
19.9	2.758
22.0	4.301
23.9	6.212
25.9	8.872
27.8	12.121
29.8	16.441
CURVE 39*,†,‡	
5.3	0.000 x 10^{-4}
5.6	0.001

T	$\Delta L/L_0$
CURVE 39 (cont.)*,†,‡	
5.9	0.002 x 10^{-4}
6.3	0.006
6.9	0.014
7.8	0.036
7.8	0.036
8.6	0.065
8.7	0.069
9.2	0.093
9.2	0.093
9.9	0.136
9.9	0.136
10.6	0.195
10.7	0.204
11.8	0.317
11.8	0.317
13.0	0.486
13.0	0.486
14.2	0.712
14.3	0.733
15.5	1.034
15.5	1.034
16.8	1.454
16.8	1.454
18.5	2.191
18.5	2.191
20.0	3.059
20.0	3.059
21.7	4.321
21.7	4.321
23.3	5.874
23.3	5.874
CURVE 40*	
293	0.00
593	1.37
CURVE 41	
293	0.00
373	0.46
419	0.64
469	0.88
516	1.08
571	1.20*
621	1.51*
670	1.72
719	2.01

T	$\Delta L/L_0$
CURVE 41 (cont.)	
772	2.28
823	2.56*
872	2.82
919	3.14
969	3.54
1023	4.09
1034	4.35
1049	4.72
CURVE 42	
293	0.000*
878	2.870*
925	3.21
982	3.73*
1004	3.83
1004	3.97*
1025	4.18*
1038	4.37
1044	4.61*
1049	4.83
CURVE 43	
273	-0.10*
293	0.00*
373	0.36*
420	0.56*
473	0.77*
527	1.01*
573	1.18*
617	1.42*
673	1.59
721	1.85
773	2.06
820	2.36
873	2.64
920	2.90
973	3.16*
990	3.27*
1014	3.41
1040	3.56
1073	3.67
CURVE 44	
293	0.00*
975	3.42

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 278. THERMAL LINEAR EXPANSION OF SODIUM CHLORIDE NaCl (continued)

T	$\Delta L/L_0$
CURVE 44 (cont.)	
989	3.52*
1006	3.69*
1024	3.90
1033	4.05*
1048	4.21*
1050	4.37*
1057	4.58
CURVE 45	
293	0.000*
300	-0.053
475	0.693*
574	1.101
678	1.563*
768	2.185*
825	2.434*
916	3.180*
961	3.464*
998	3.642
1026	3.979
1049	4.566
CURVE 46	
293	0.000*
470	0.799*
659	1.634*
863	2.754*
972	3.340
1047	4.299
CURVE 47	
293	0.000*
570	1.171*
671	1.615*
760	1.917
843	2.538
953	3.195
CURVE 48*	
293	0.000
690	1.865
806	2.523
926	3.056
999	3.837
1032	4.388

* Not shown in figure.

DATA TABLE 278. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM CHLORIDE NaCl

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
7	0.021*
8	0.022
9	0.043*
10	0.061*
11	0.080*
12	0.104*
13	0.135*
14	0.173*
15	0.22
16	0.27*
17	0.34*
18	0.42*
19	0.50*
20	0.60*
22	0.84*
24	1.15*
26	1.53
28	1.99*
30	2.48
32	3.02*
34	3.61*
36	4.30*
38	5.00*
40	5.74
45	7.70*
50	9.75*
55	11.82
60	13.80*
65	15.63*
70	17.42
80	20.50*
90	23.15*
100	25.25
125	29.40
175	32.10
200	34.29
250	38.02
290	39.50
CURVE 2‡	
223	43
233	45
253	45
273	44
293	44

T	α
CURVE 2 (cont.)‡	
313	44
333	44
353	44
373	44
393	44
413	44
433	44
453	44
473	44
CURVE 6‡	
6	0.012
7	0.02
8	0.03
10	0.06
12	0.11
14	0.18
16	0.29
18	0.42
20	0.62
22	0.86
24	1.15
26	1.52
28	1.94
30	2.43
35.75	12.93
65	15.8
75	19.0
85	22.0
283	39.5
CURVE 7‡	
24	0.2*
27	0.7
31	1.2*
33	2.1*
37	2.6*
40	4.2
41	3.3*
42	5.0
43	4.0
48	6.2
49	8.1*
53	10.2

T	α
CURVE 7 (cont.)‡	
55	10.7*
57	11.7*
61	12.8
67	15.5*
67	16.7
69	16.1*
74	17.3*
76	18.3
80	21.4*
85	21.4
93	23.9
105	26.5
115	28.7
122	29.7
132	30.1
134	31.2*
141	31.7
145	32.2
165	34.2
167	33.2*
173	33.9
177	33.9*
183	33.7
187	34.8*
199	35.3
203	36.4
211	36.7*
217	36.5
226	37.4
228	38.1
238	37.5
242	37.6*
250	38.1
257	38.9*
264	39.4
268	38.4
280	39.7
CURVE 15*	
317.50	37.31
369.93	40.83
427.97	40.05
483.93	43.56
590.77	46.78
636.44	47.86

T	α
CURVE 15 (cont.)*	
688.64	49.32
740.04	51.87
789.50	52.24
834.71	52.60
859.23	49.99
CURVE 16*	
317.50	33.70
369.93	40.32
427.97	38.64
483.93	42.68
590.77	46.90
636.44	48.32
688.64	50.13
740.04	52.52
789.50	54.56
834.71	52.72
859.23	56.73
CURVE 17*	
313.6	32.57
362.3	36.93
417.1	41.88
422.4	45.33
477.9	45.86
484.6	29.60
534.8	48.82
541.9	49.00
590.3	49.31
640.1	58.38
CURVE 18*,‡	
313.6	20.44
362.3	36.20
417.1	43.31
422.4	40.86
477.9	44.88
484.6	31.51
534.8	47.36
541.9	27.30
590.3	24.99
640.1	24.32

T	α
CURVE 21‡	
10	0.057
12	0.100*
14	0.168*
16	0.260*
18	0.394*
20	0.574*
22	0.824*
24	1.15*
26	1.53*
28	1.99*
30	2.48*
32	3.02*
34	3.61*
36	4.30*
38	5.00*
40	5.74*
45	7.70
50	9.75
55	11.8*
60	13.8
65	15.6*
70	17.4*
80	20.50
90	23.15
100	25.25*
125	29.4*
150	32.1*
174.2	34.21
245.4	37.85
259.1	38.30
285.55	39.33
CURVE 22	
92.30	22.45
102.36	24.62
111.35	26.59
111.59	26.49
122.88	28.57
137.86	30.61
152.42	32.17
152.69	32.15*
167.21	33.33
182.40	34.23
178.15	34.02
199.95	35.58*

T	α
CURVE 22 (cont.)	
218.38	36.39*
239.51	37.32*
259.71	38.22*
279.65	39.68*
CURVE 23‡	
19.84	0.48
26.473	1.56*
27.49	1.76*
29.05	2.01*
34.71	3.75
36.41	4.22*
44.86	7.28
52.74	10.89
61.13	13.98*
69.56	17.15*
77.37	19.49
74.83	18.86*
84.342	21.84*
86.80	22.26*
95.57	24.11
97.81	24.55*
111.88	27.35
126.35	29.49*
141.72	31.37*
159.97	33.15
180.12	34.55*
202.80	35.88
230.21	37.28
259.95	38.38*
289.73	39.70
CURVE 24‡	
140	29.7
152	31.7
163.4	33.8*
185.2	35.1*
206.0	35.9*
226.7	36.8*
246.4	37.9*
263.9	39.6*
287.1	40.2*
315.2	40.3
353.2	41.3

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 278. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM CHLORIDE NaCl (continued)

T	α
CURVE 24 (cont.)‡	
390.2	43.4
425.2	44.7
456.2	46.6
489.2	47.6
521.2	49.5
550	50.6
CURVE 27‡	
85	22.78
100	25.37
120	28.43
140	31.03*
160	32.94
180	34.78*
200	35.43*
220	36.41
240	37.42*
260	38.34*
280	39.16
300	39.86*
310	40.16
CURVE 28*,‡	
293	40.2
326	41.1
375	42.7
475	45.7
574	48.4
675	52.1
774	55.5
823	57.2
873	59.4
921	61.8
971	65.7
1021	70.6
1040	72.6
CURVE 29‡	
2.735	0.0023
3.775	0.0033
4.489	0.0054
5.065	0.0077
5.194	0.0080
5.748	0.0111
5.909	0.0121

T	α
CURVE 29 (cont.)‡	
6.491	0.0159
6.544	0.0168
7.211	0.0220
7.884	0.0286
8.661	0.0385
9.458	0.0504
10.073	0.0614
10.627	0.0728
11.155	0.0844
11.737	0.1006
12.400	0.1182
13.086	0.1438
13.816	0.1716
14.656	0.2080
15.642	0.2605
16.713	0.3265
17.853	0.4090
19.102	0.5178
20.458	0.6590
21.820	0.8260
23.039	1.0040
24.210	1.1900
25.446	1.4140
26.768	1.6810
28.262	2.0200
29.901	2.4180
58.000	12.9000
65.000	15.5400
75.000	18.9000
85.000	21.8100
283.000	39.1000
CURVE 30*,‡	
293	38.2
300	39.2
400	43.6
500	48.9
600	53.9
700	58.9
800	63.7
900	68.3
1003	72.8
CURVE 31‡	
67	21.5
78	23.1

T	α
CURVE 31 (cont.)‡	
94	25.1
108	27.0
118	28.1
146	30.4
169	32.8
196	34.5
229	36.0
273	37.9
293	38.7
300	38.9
324	39.3*
374	40.6*
424	42.2*
474	44.0*
523	46.5*
550	49.6*
576	51.0*
CURVE 32‡	
3.000	0.001
3.250	0.002
3.750	0.003
4.375	0.004
4.875	0.006
5.500	0.009
6.500	0.016
7.000	0.020
7.500	0.025
8.500	0.036
9.500	0.051
10.500	0.071
11.500	0.095
12.500	0.124
13.000	0.141
14.500	0.202
16.001	0.283
18.000	0.425
20.000	0.661
22.000	0.860
24.000	1.162
26.000	1.529
28.000	1.957
30.000	2.463

T	α
CURVE 33‡	
2.70	0.001
3.00	0.001
3.40	0.002
3.75	0.003
4.15	0.004
4.45	0.005
4.50	0.005
4.50	0.005
4.80	0.006
5.20	0.008
6.00	0.013
7.00	0.020
8.00	0.031
9.00	0.044
10.50	0.072
11.50	0.095
13.00	0.142
15.00	0.228
20.00	0.619
25.00	1.347
30.00	2.480
CURVE 34‡	
2.225	0.007
2.625	0.007
3.125	0.008
3.750	0.009
4.500	0.011
5.000	0.014
5.500	0.016
6.000	0.019
6.500	0.022
7.000	0.026
8.000	0.036
8.500	0.042
9.000	0.049
10.000	0.066
11.200	0.092
12.300	0.122
13.400	0.160
15.500	0.258
19.500	0.568
24.700	1.292
29.900	2.447

T	α
CURVE 35‡	
145	26.7
156	29.1
180	31.7
207	31.7
231	33.0
262	34.7
267	35.3
275	37.6
280	38.6
293	40.4
300	40.6
317	41.4*
408	44.0*
457	44.9*
489	44.7*
513	46.5*
595	47.4*
625	47.7*
707	49.9*
CURVE 36‡	
3.9	0.003
4.3	0.004
5.2	0.008
5.2	0.008
5.8	0.011
6.5	0.016
7.2	0.021
7.8	0.027
8.7	0.039
9.6	0.052
10.3	0.065
11.2	0.084
11.6	0.097
12.5	0.120
13.1	0.144
13.6	0.163
14.7	0.209
15.6	0.258
17.9	0.412
19.1	0.517
20.4	0.655
21.9	0.836
24.3	1.207
25.7	1.462
26.8	1.692
28.4	2.050

T	α
CURVE 37‡	
4.0	0.000
4.5	0.002
4.9	0.004
5.2	0.006
5.6	0.008
5.9	0.010
6.3	0.012
6.7	0.017
7.2	0.021
7.8	0.026
8.4	0.034
9.2	0.045
9.9	0.058
10.7	0.073
11.8	0.098
12.9	0.132
13.9	0.177
15.1	0.232
16.5	0.314
18.2	0.443
19.6	0.575
21.2	0.758
23.0	0.997
24.9	1.312
CURVE 38‡	
3.2	0.001
3.3	0.002
3.9	0.003
4.4	0.004
4.8	0.006
5.6	0.010
6.6	0.016
7.0	0.020
7.6	0.026
8.7	0.039
9.4	0.056
10.6	0.073
11.5	0.094
11.6	0.097
12.4	0.121
13.0	0.141
14.5	0.203
16.0	0.283
18.0	0.426
19.9	0.607
22.0	0.862

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 278. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM CHLORIDE NaCl (continued)

T	α
CURVE 38 (cont.)‡	
23.9	1.150
25.9	1.510
27.8	1.910
29.8	2.410
CURVE 39‡	
5.3	0.000
5.6	0.004
5.9	0.006
6.3	0.010
6.9	0.018
7.8	0.030
7.8	0.030
8.6	0.041
8.7	0.042
9.2	0.053
9.2	0.054
9.9	0.068
9.9	0.085
10.6	0.085
10.7	0.088
11.8	0.117
11.8	0.119
13.0	0.162
13.0	0.165
14.2	0.212
14.3	0.221
15.5	0.280
15.5	0.284
16.8	0.362
16.8	0.365
18.5	0.502
18.5	0.511
20.0	0.646
20.0	0.633
21.7	0.852
21.7	0.867
23.3	1.074
23.3	1.098

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 279. THERMAL LINEAR EXPANSION OF POTASSIUM CHLORIDE + RUBIDIUM CHLORIDE KCl + RbCl

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) KCl	RbCl	Composition (continued), Specifications, and Remarks
1*	481	McKinstry, H.A.	1960	X	300-572		64.7	35.2	Solid composition of KCl and RbCl; rubidium chloride prepared from a chemically pure $RbCO_3$ and pure hydrochloride acid; lattice parameter reported at 300 K as 6.3715 Å; 6.3712 Å at 293 K determined by graphical extrapolation.
2*	481	McKinstry, H.A.	1960	X	299-574		17.04	82.95	Solid solution; 82.95 RbCl prepared from chemically pure $RbCO_3$ and hydrochloric acid and 11.04 KCl; lattice parameter extrapolated to reduce systematic error; lattice parameter reported at 298.7 K as 6.5178 Å; 6.5166 Å at 293 K determined by graphical extrapolation.
3*	481	McKinstry, H.A.	1960	X	303-474		38.1	61.8	Similar to the above specimen except 61.8 RbCl and 38.1 KCl; lattice parameter reported at 303 K as 6.4430 Å; 6.4406 Å at 293 K determined by graphical extrapolation.
4*	481	McKinstry, H.A.	1960	X	301-577		38.1	61.8	The above specimen; lattice parameter reported at 301 K as 6.4447 Å; 6.4427 Å at 293 K determined by graphical extrapolation.

DATA TABLE 279. THERMAL LINEAR EXPANSION OF POTASSIUM CHLORIDE + RUBIDIUM CHLORIDE KCl + RbCl

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
299.70	0.004
301.20	0.005
375.45	0.279
423.70	0.475
472.95	0.692
524.45	0.908
571.70	1.12

CURVE 2*

T	$\Delta L/L_0$
298.70	0.016
300.95	0.023
371.20	0.282
425.45	0.497
471.95	0.691
477.45	0.703
521.45	0.900
573.95	1.140

CURVE 3*

T	$\Delta L/L_0$
303.45	0.039
369.95	0.286
426.20	0.517
473.95	0.707

CURVE 4*

T	$\Delta L/L_0$
300.70	0.030
423.20	0.504
472.95	0.711
521.70	0.912
577.20	1.17

* No figure given.

SPECIFICATION TABLE 280. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CHLORIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	748	Donaldson, R. H. and Lanchester, P. C.	1967	E	1.5-4.0	$CoCl_2 \cdot 6H_2O$	Cobalt dichloride; dimensions: 1 to 2 mm long; single crystal, grown by slow evaporation from aqueous solution, monoclinic structure; measurements along a-axis; this curve is here reported using 4.0 K as the reference temperature at which $\Delta L/L_0 = 0$.
2*	748	Donaldson, R. H. and Lanchester, P. C.	1967	E	1.5-4.0	$CoCl_2 \cdot 6H_2O$	Cobalt dichloride; the above specimen measured along b-axis; this curve is here reported using 4.0 K as the reference temperature at which $\Delta L/L_0 = 0$.
3*	748	Donaldson, R. H. and Lanchester, P. C.	1967	E	1.5-4.0	$CoCl_2 \cdot 6H_2O$	Cobalt dichloride; the above specimen measured along c-axis; this curve is here reported using 4.0 K as the reference temperature at which $\Delta L/L_0 = 0$.
4*	748	Donaldson, R. H. and Lanchester, P. C.	1967	E	1.5-4.0	$CoCl_2 \cdot 6H_2O$	Cobalt dichloride; similar to the above specimen except expansion measured along a-axis; it was necessary to cement three crystals together with a thin layer of GE 7031 varnish; this curve is here reported using 4.0 K as the reference temperature at which $\Delta L/L_0 = 0$.
5*	748	Donaldson, R. H. and Lanchester, P. C.	1967	E	1.5-4.0	$CoCl_2 \cdot 6H_2O$	Similar to the above specimen except expansion measured along c-axis; this curve is here reported using 4.0 K as the reference temperature at which $\Delta L/L_0 = 0$.
6*	160	Schaake, H. F.	1969	X	4.2-299	CuCl	Copper chloride; specimen from Fisher C-457, powder ground to < 325 mesh; 10% iridium added for calibration; pressed into copper sample holder, annealed 2 hr at 473 K; lattice parameter reported at 298.6 K as 5.4163 Å; 5.4156 Å at 293 K determined by graphical interpolation.
7*	632	Bridgman, P. W.	1932		303, 348	CuCl	Copper chloride; specimen pressed in a 0.375 in. diameter x 0.375-0.500 in. long cylinder; lever piezometer method was used to measure expansion.
8*	749	Blairs, S. and Shelton, R. A. J.	1966	X	291-548	$FeCl_3$	Iron III chloride; sample prepared by chlorination of Remco iron and purified by multiple sublimation in chlorine; unfiltered cobalt K (alpha) radiation employed; lattice parameter expansion measured along a-axis; 6.0649 Å reported at 291 K; 6.0653 Å at 293 K determined by graphical interpolation.
9*	749	Blairs, S. and Shelton, R. A. J.	1966	X	291-548	$FeCl_3$	Iron III chloride; the above specimen; lattice parameter expansion measured along c-axis; 17.443 Å reported at 291 K; 17.444 Å at 293 K determined by graphical interpolation.
10*	295	Hsu, Y. T.	1967	X	291-767	PbFCl	Lead fluorochloride; powder of tetragonal crystal prepared from reagent grade materials; placed in 0.3 mm diameter capillary; expansion measured along a-axis; lattice parameter reported at 291 K as 4.104 Å; 4.106 Å at 293 K determined by graphical extrapolation.
11*	295	Hsu, Y. T.	1967	X	291-767	PbFCl	Lead fluorochloride; the above specimen; expansion measured along c-axis; lattice parameter reported at 291 K as 7.227 Å; 7.227 Å at 293 K is determined by graphical extrapolation.
12*	750	Gonano, R., Philp, J. W., and Adams, E. D.	1968	E	0.5-4.00	$MnCl_2 \cdot 4H_2O$	Manganese dichloride tetrahydrate; sample a cube cut from the optically perfect part of a crystal, grown by evaporation of water from a saturated solution; cube edges parallel to the a, b, c' axes; linear thermal expansion measured along the "a" axis, λ anomaly due to antiferromagnetic ordering at 1.622 K; reported error 10%; this curve is here reported using 4 K as the reference temperature at which $\Delta L/L_0 = 0$.
13*	750	Gonano, R., et al.	1968	E	0.5-4.00	$MnCl_2 \cdot 4H_2O$	Manganese dichloride tetrahydrate; the above specimen; linear thermal expansion measured along the "b" axis; this curve is here reported using 4 K as the reference temperature at which $\Delta L/L_0 = 0$.

* No figure given.

SPECIFICATION TABLE 280. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CHLORIDES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
14*	750	Gonano, R., Philp, J.W., and Adams, E.D.	1968	E'	0.5-4.00	$MnCl_2 \cdot 4H_2O$	Manganese dichloride tetrahydrate; the above specimen; linear thermal expansion measured along axis "c'" perpendicular to axes "a" and "b"; this curve is here reported using 4 K as the reference temperature at which $\Delta L/L_0 = 0$.
15*	627	Philp, J.W., Gonano, R., and Adams, E.D.	1969	E'	0.50-4.00	$MnCl_2 \cdot 4H_2O$	Manganese dichloride tetrahydrate; sample 0.6 cm cube cut with wet wire from crystal which was grown by evaporation from saturated solution, cut axes parallel to a, b, c' axes, no visible flaws; measured in a-axis direction; this curve is here reported using 4 K as the reference temperature at which $\Delta L/L_0 = 0$.
16*	627	Philp, J.W., et al.	1969	E'	0.50-4.2	$MnCl_2 \cdot 4H_2O$	Manganese dichloride tetrahydrate; the above specimen; measured in b-axis direction; this curve is here reported using 4 K as the reference temperature at which $\Delta L/L_0 = 0$.
17*	627	Philp, J.W., et al.	1969	E'	0.50-4.0	$MnCl_2 \cdot 4H_2O$	Manganese dichloride tetrahydrate; the above specimen; measured in c'-axis direction perpendicular to both and and b axes; this curve is here reported using 4 K as the reference temperature at which $\Delta L/L_0 = 0$.
18*	751	Philp, J.W.	1967		0.55-3.9	$MnCl_2 \cdot 4H_2O$	Manganese dichloride tetrahydrate; concentrated solution made using "Baker Analyzed" reagent 99.2% and distilled water; crystal evaporated from solvent; measured in c'-direction; this curve is here reported using 4 K as the reference temperature at which $\Delta L/L_0 = 0$.
19*	751	Philp, J.W.	1967		0.70-1.10	$MnCl_2 \cdot 4H_2O$	Manganese dichloride tetrahydrate; similar to the above specimen; another run; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
20*	751	Philp, J.W.	1967		1.15-1.74	$MnCl_2 \cdot 4H_2O$	Manganese dichloride tetrahydrate; similar to the above specimen; another run; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
21*	751	Philp, J.W.	1967		1.60-1.61	$MnCl_2 \cdot 4H_2O$	Manganese dichloride tetrahydrate; similar to the above specimen; another run; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
22*	751	Philp, J.W.	1967		1.60-1.64	$MnCl_2 \cdot 4H_2O$	Manganese dichloride tetrahydrate; similar to the above specimen; another run; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
23*	751	Philp, J.W.	1967		1.60-1.64	$MnCl_2 \cdot 4H_2O$	Manganese dichloride tetrahydrate; similar to the above specimen; another run; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
24*	751	Philp, J.W.	1967		0.50-3.5	$MnCl_2 \cdot 4H_2O$	Manganese dichloride tetrahydrate; the above specimen; measured in a-direction; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
25*	773	Khan, A.A. and Deshpande, V.T.	1968	X	299-567	$SrCl_2$	Strontium dichloride; hydrated ($SrCl_2 \cdot 6H_2O$) heated 3 hr at 573 K to obtain cubic anhydrous powder specimen; lattice parameter reported at 299 K as 6.9792 Å; 6.9788 Å at 293 K determined by graphical extrapolation.
26*	295	Hsu, Y.T.	1967	X	288-701	TlCl	Thallium chloride; reagent grade specimen, powder in 0.3 mm diameter capillary; lattice parameter expansion measured along a-axis; 3.843 Å reported at 288 K; 3.844 Å at 293 K determined by graphical interpolation.

* No figure given.

SPECIFICATION TABLE 280. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CHLORIDES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
27*	665	Johnson, R.W.	1967		293, 333	TlCl	Thallium chloride; no details given.
28*	322	Combes, L.S., Ballard, S.S., and McCarthy, K.A.	1951	L	223-473	(KRS-6)	Sample obtained from the Engineer Research and Development Laboratories; bar specimen.
29*	322	Combes, L.S., et al.	1951	L	223-473	(KRS-6)	The above specimen; average values.
30*	665	Johnson, R.W.	1967		293, 373	(KRS-6)	No details given.
31*	747	Fullam, H.T.	1972		298, 573	CsCl + ΣX_i	Cesium chloride mixtures; 90 CsCl, 10 KCl; specimens were reagent grade; weighed amounts were combined and ball-milled; the mixture was heated and again ball-milled to a fine powder, this was melted and cast into pyrex tubes; ends of specimen were made parallel to each other.
32*	747	Fullam, H.T.	1972		298, 573	CsCl + ΣX_i	Cesium chloride mixtures; similar to the above specimen except 90 CsCl, 5 KCl, 5 NaCl.
33*	747	Fullam, H.T.	1972		298, 573	CsCl + ΣX_i	Cesium chloride mixtures; similar to the above specimen except 90 CsCl, 10 NaCl.
34*	747	Fullam, H.T.	1972		298, 573	CsCl + ΣX_i	Cesium chloride mixtures; similar to the above specimen except 70 CsCl, 30 KCl.
35*	747	Fullam, H.T.	1972		298, 573	CsCl + ΣX_i	Cesium chloride mixtures; similar to the above specimen except 70 CsCl, 20 KCl, 10 NaCl.
36*	747	Fullam, H.T.	1972		298, 573	CsCl + ΣX_i	Cesium chloride mixtures; similar to the above specimen except 70 CsCl, 15 KCl, 15 NaCl.
37*	747	Fullam, H.T.	1972		298, 573	CsCl + ΣX_i	Cesium chloride mixtures; similar to the above specimen except 70 CsCl, 10 KCl, 20 NaCl.
38*	747	Fullam, H.T.	1972		298, 573	CsCl + ΣX_i	Cesium chloride mixtures; similar to the above specimen except 70 CsCl, 30 NaCl.

* No figure given.

DATA TABLE 280. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CHLORIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*,‡	
1.5	-0.69×10^{-2}
1.6	-0.69
1.7	-0.68
1.8	-0.67
1.9	-0.65
2.0	-0.63
2.1	-0.61
2.15	-0.60
2.20	-0.57
2.25	-0.54
2.275	-0.53
2.35	-0.50
2.4	-0.49
2.5	-0.47
2.6	-0.46
2.8	-0.40
3.0	-0.31
3.2	-0.24
3.4	-0.17
3.6	-0.11
3.8	-0.05
4.0	0.00
CURVE 2*,‡	
1.5	-1.4×10^{-2}
1.6	-1.4
1.7	-1.354
1.8	-1.29
1.9	-1.23
2.0	-1.15
2.1	-1.05
2.15	-0.988
2.20	-0.915
2.25	-0.827
2.275	-0.773
2.35	-0.655
2.4	-0.618
2.5	-0.554
2.6	-0.497
2.8	-0.400
3.0	-0.310
3.2	-0.240
3.4	-0.170
3.6	-0.110
3.8	-0.05
4.0	0.00

T	$\Delta L/L_0$
CURVE 3*,‡	
1.5	-0.540×10^{-3}
1.6	-0.535
1.7	-0.525
1.8	-0.513
1.9	-0.499
2.0	-0.482
2.1	-0.463
2.15	-0.453
2.20	-0.442
2.275	-0.420
2.35	-0.390
2.4	-0.380
2.5	-0.340
2.6	-0.310
2.8	-0.240
3.0	-0.190
3.2	-0.140
3.4	-0.100
3.6	-0.060
3.8	-0.030
4.0	0.000
CURVE 4*,‡	
1.5	-0.068×10^{-3}
1.6	-0.0605
1.7	-0.0430
1.8	0.0230
1.9	0.002
2.0	0.033
2.1	0.075
2.15	0.1
2.20	0.131
2.25	0.174
2.35	0.225
2.4	0.222
2.5	0.208
2.6	0.192
2.8	0.158
3.0	0.123
3.2	0.09
3.4	0.062
3.6	0.038
3.8	0.018
4.0	0.000

T	$\Delta L/L_0$
CURVE 5*,‡	
1.5	-1.090×10^{-3}
1.6	-1.070
1.7	-0.040
1.8	-0.993
1.9	-0.932
2.0	-0.855
2.1	-0.754
2.15	-0.687
2.20	-0.600
2.35	-0.417
2.40	-0.394
2.50	-0.353
2.60	-0.316
2.80	-0.251
3.00	-0.197
3.20	-0.150
3.40	-0.108
3.60	-0.07
3.80	-0.03
4.00	0.00
CURVE 6*	
4.2	-0.117
20	-0.123
40	-0.145
60	-0.158
77.4	-0.164
100	-0.164
120.5	-0.162
150.5	-0.153
194.5	-0.116
240	-0.071
273	-0.030
298.6	0.008
CURVE 7*	
303	0.022
348	0.120
CURVE 8*	
291	-0.007
312	0.066
337.5	0.106
360	0.127

T	$\Delta L/L_0$
CURVE 8 (cont.)*	
385.5	0.209
412	0.247
441.5	0.315
466.5	0.333
495.5	0.376
522	0.4303
548	0.5227
CURVE 9*	
291	-0.0057
312	0.0516
337.5	0.2178
360	0.2809
385.5	0.4185
412	0.4930
441.5	0.6191
466.5	0.7108
495.5	0.8140
522	0.9631
548	1.0949
CURVE 10*	
291	-0.005
310	0.044
329	0.165
385	0.239
402	0.360
409	0.458
453	0.531
501	0.653
538	0.726
583	0.848
623	1.018
652	1.164
688	1.286
720	1.432
756	1.603
767	1.725
CURVE 11*	
291	-0.003
310	0.025
329	0.108
385	0.246

T	$\Delta L/L_0$
CURVE 11 (cont.)*	
402	0.301
409	0.398
452	0.495
501	0.606
538	0.827
583	0.993
623	1.090
652	1.104
688	1.159
720	1.298
756	1.353
767	1.367
CURVE 12*,‡	
0.50	-1.20×10^{-3}
0.91	-1.084
1.11	-0.946
1.27	-0.799
1.35	-0.709
1.44	-0.587
1.52	-0.456
1.56	-0.378
1.60	-0.285
1.61	-0.258
1.62	-0.225
1.62	-0.225
1.63	-0.216
1.66	-0.197
1.73	-0.168
1.80	-0.149
2.02	-0.111
2.55	-0.058
4.00	0.000
CURVE 13*,‡	
0.5	-2.510×10^{-3}
0.75	-2.371
0.90	-2.336
1.01	-2.104
1.11	-1.958
1.20	-1.805
1.29	-1.627
1.37	-1.444
1.44	-1.261
1.50	-1.083

T	$\Delta L/L_0$
CURVE 13 (cont.)*,‡	
1.54	-0.948
1.57	-0.833
1.60	-0.698
1.61	-0.640
1.61	-0.640
1.63	-0.536
1.63	-0.536
1.65	-0.502
1.66	-0.489
1.69	-0.458
1.75	-0.411
1.85	-0.353
1.95	-0.309
2.07	-0.269
2.22	-0.230
2.84	-0.116
4.00	0.000
CURVE 14*,‡	
0.50	-0.660×10^{-3}
0.93	-0.572
1.32	-0.412
1.44	-0.344
1.52	-0.289
1.59	-0.228
1.61	-0.206
1.61	-0.206
1.61	-0.206
1.67	-0.183
1.74	-0.168
2.55	-0.079
4.00	0.000
CURVE 15*,‡	
0.5	1.050×10^{-3}
0.6	1.024
0.7	0.988
0.8	0.944
0.9	0.890
1.0	0.826
1.1	0.751
1.2	0.663
1.3	0.561
1.4	0.438
1.8	0.121

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 280. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CHLORIDES (continued)

T	$\Delta L/L_0$
CURVE 15 (cont.)*,‡	
1.9	0.100×10^{-3}
2.0	0.084
2.1	0.072
2.2	0.062
2.3	0.054
2.4	0.046
2.5	0.040
2.6	0.035
2.7	0.030
2.8	0.026
2.9	0.022
3.0	0.019
3.1	0.016
3.2	0.013
3.3	0.011
3.4	0.009
3.5	0.007
3.6	0.005
3.7	0.003
3.8	0.002
3.9	0.001
4.0	0.000
CURVE 16*,‡	
0.5	-2.092×10^{-3}
0.6	-2.046
0.7	-1.984
0.8	-1.905
0.9	-1.808
1.0	-1.692
1.1	-1.555
1.2	-1.393
1.3	-1.201
1.4	-0.970
1.8	-0.352
1.9	-0.303
2.0	-0.265
2.1	-0.235
2.2	-0.209
2.3	-0.186
2.4	-0.166
2.5	-0.147
2.6	-0.131
2.7	-0.116
2.8	-0.102
2.9	-0.090
3.0	-0.078
3.1	-0.068

T	$\Delta L/L_0$
CURVE 16 (cont.)*,‡	
3.2	-0.058×10^{-3}
3.3	-0.049
3.4	-0.041
3.5	-0.033
3.6	-0.026
3.7	-0.019
3.8	-0.012
3.9	-0.006
4.0	0.000
4.1	0.006
4.2	0.012
CURVE 17*,‡	
0.5	-0.501×10^{-3}
0.6	-0.488
0.7	-0.471
0.8	-0.450
0.9	0.425
1.0	0.394
1.1	0.359
1.2	0.318
1.3	0.271
1.4	0.217
1.8	0.075
1.9	0.064
2.0	0.055
2.1	0.048
2.2	0.042
2.3	0.037
2.4	0.033
2.5	0.029
2.6	0.025
2.7	0.022
2.8	0.019
2.9	0.017
3.0	0.014
3.1	0.012
3.2	0.010
3.3	0.008
3.4	0.007
3.5	0.005
3.6	0.004
3.7	0.003
3.8	0.002
3.9	0.001
4.0	0.000

T	$\Delta L/L_0$
CURVE 18*,‡	
0.55	-0.556×10^{-3}
0.60	-0.549
0.65	-0.541
0.70	-0.532
0.75	-0.522
0.80	-0.511
0.85	-0.499
0.90	-0.485
0.95	-0.469
1.00	-0.453
1.05	-0.434
1.10	-0.415
1.15	-0.394
1.20	-0.372
1.25	-0.349
1.30	-0.323
1.35	-0.295
1.40	-0.264
1.45	-0.230
1.75	-0.102
1.80	-0.095
1.85	-0.089
1.90	-0.083
1.95	-0.078
2.00	-0.073
2.10	-0.064
2.20	-0.056
2.30	-0.049
2.40	-0.044
2.50	-0.040
2.60	-0.035
2.70	-0.031
2.80	-0.027
2.90	-0.024
3.00	-0.021
3.10	-0.018
3.20	-0.015
3.30	-0.013
3.40	-0.011
3.50	-0.009
3.60	-0.007
3.70	-0.005
3.80	-0.003
3.90	-0.001
CURVE 19*,‡	
0.70	0.0000×10^{-3}
0.75	0.0105

T	$\Delta L/L_0$
CURVE 19 (cont.)*,‡	
0.80	0.0227×10^{-3}
0.85	0.0362
0.90	0.0509
0.95	0.0668
1.00	0.0842
1.05	0.1028
1.10	0.1223
CURVE 20*,‡	
1.150	0.0000×10^{-3}
1.200	0.0225
1.250	0.0461
1.300	0.0711
1.350	0.0976
1.400	0.1259
1.450	0.1566
1.500	0.1913
1.510	0.1987
1.520	0.2063
1.530	0.2140
1.540	0.2218
1.550	0.2299
1.552	0.2316
1.558	0.2370
1.564	0.2429
1.577	0.2584
1.583	0.2648
1 589	0.2696
1.595	0.2760
1.600	0.2827
1.606	0.2899
1.613	0.2996
1.616	0.3045
1.626	0.3134
1.642	0.3171
1.656	0.3210
1.673	0.3248
1.680	0.3262
1.690	0.3281
1.700	0.3300
1.710	0.3318
1.720	0.3335
1.730	0.3352
1.740	0.3369
CURVE 21*,‡	
1.6002	0.00×10^{-5}

T	$\Delta L/L_0$
CURVE 21 (cont.)*,‡	
1.6041	0.37×10^{-5}
1.6067	0.67
1.6083	0.79
1.6092	0.84
1.6113	1.04
1.6132	1.24
1.6141	1.34
CURVE 22*,‡	
1.6006	0.000×10^{-4}
1.6045	0.034
1.6074	0.058
1.6100	0.086
1.6126	0.116
1.6147	0.141
1.6166	0.157
1.6178	0.165
1.6184	0.171
1.6189	0.176
1.6192	0.178
1.6197	0.182
1.6203	0.182
1.6209	0.183
1.6219	0.188
1.6236	0.194
1.6255	0.198
1.6283	0.206
1.6315	0.217
1.6355	0.228
CURVE 23*,‡	
1.6023	0.000×10^{-4}
1.6049	0.027
1.6072	0.048
1.6095	0.076
1.6118	0.108
1.6144	0.145
1.6165	0.175
1.6176	0.186
1.6175	0.185
1.6179	0.190
1.6184	0.196
1.6186	0.200
1.6190	0.207
1.6208	0.221
1.6210	0.222
1.6218	0.226

T	$\Delta L/L_0$
CURVE 23 (cont.)*,‡	
1.6226	0.231×10^{-4}
1.6232	0.234
1.6241	0.236
1.6249	0.244
1.6257	0.255
1.6270	0.261
1.6284	0.268
1.6293	0.272
1.6310	0.277
1.6323	0.282
1.6338	0.288
1.6353	0.292
CURVE 24*,‡	
0.5000	0.000×10^{-3}
0.5500	-0.012
0.6000	-0.024
0.6500	-0.037
0.7000	-0.052
0.7500	-0.068
0.8000	-0.086
0.8500	-0.105
0.9000	-0.126
0.9500	-0.149
1.0000	-0.174
1.0500	-0.201
1.1000	-0.231
1.1500	-0.262
1.2000	-0.294
1.2500	-0.330
1.3000	-0.369
1.3500	-0.410
1.4000	-0.455
1.4500	-0.508
1.4600	-0.520
1.4700	-0.533
1.4800	-0.547
1.4900	-0.561
1.5000	-0.575
1.5100	-0.589
1.5200	-0.602
1.5300	-0.617
1.5400	-0.631
1.5500	-0.645
1.5600	-0.659
1.5700	-0.674
1.5800	-0.689
1.5900	-0.705

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 280. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CHLORIDES (continued)

T	$\Delta L/L_0$
CURVE 24 (cont.)*,‡	
1.6000	-0.724×10^{-3}
1.6100	-0.745
1.6160	-0.759
1.6170	-0.762
1.6180	-0.764
1.6190	-0.767
1.6200	-0.770
1.6204	-0.771
1.6208	-0.772
1.6212	-0.774
1.6216	-0.775
1.6220	-0.776
1.6223	-0.776
1.6226	-0.777
1.6231	-0.778
1.6236	-0.778
1.6240	-0.779
1.6244	-0.779
1.6248	-0.779
1.6250	-0.779
1.6260	-0.780
1.6270	-0.781
1.6280	-0.782
1.6290	-0.783
1.6300	-0.783
1.6310	-0.784
1.6320	-0.784
1.6400	-0.789
1.6500	-0.793
1.6600	-0.797
1.6700	-0.801
1.6800	-0.804
1.6900	-0.807
1.7000	-0.810
1.7200	-0.815
1.7400	-0.820
1.7600	-0.824
1.7800	-0.828
1.8000	-0.832
1.8200	-0.835
1.9000	-0.846
2.0000	-0.858
2.1000	-0.867
2.2000	-0.875
2.3000	-0.881
2.4000	-0.886
2.5000	-0.891
2.6000	-0.895
2.7000	-0.898
2.8000	-0.902×10^{-3}
2.9000	-0.904
3.0000	-0.907
3.1000	-0.909
3.2000	-0.911
3.3000	-0.913
3.4000	-0.915
3.5000	-0.917
CURVE 25*	
299	0.0189
327	0.0776
347	0.128
360	0.168
385	0.221
403	0.254
447	0.344
490	0.457
519	0.543
546	0.608
567	0.662
CURVE 26*	
288	-0.026
296	0.026
315	0.182
340	0.338
365	0.494
396	0.624
437	0.806
474	1.015
513	1.223
548	1.457
577	1.665
607	1.847
638	1.951
641	2.185
673	2.211
701	2.263
CURVE 27*	
293	0.000
333	0.212
CURVE 28*,‡	
223	-0.384
233	-0.329
253	-0.217
273	-0.106
293	0.000
313	0.099
333	0.196
353	0.296
373	0.400
393	0.509
413	0.622
433	0.737
453	0.854
473	0.972
CURVE 29*	
223	-0.364
293	0.000
373	0.416
473	0.031
CURVE 30*	
293	0.000
373	0.400
CURVE 31*	
298	0.024
573	1.455
CURVE 32*	
298	0.024
573	1.455
CURVE 33*	
298	0.024
573	1.482
CURVE 34*	
298	0.022
573	1.356
CURVE 35*	
298	0.022
573	1.362
CURVE 36*	
298	0.022
573	1.365
CURVE 37*	
298	0.022
573	1.371
CURVE 38*	
298	0.023
573	1.389

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 280. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS CHLORIDES

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

CURVE 1*,‡

T	α
1.6	0.87
1.7	1.1
1.8	1.37
1.9	1.74
2.0	2.16
2.1	2.75
2.15	3.4
2.20	5.8
2.25	6.45
2.275	5.9
2.35	1.8
2.4	1.75
2.5	1.45
2.6	1.4
2.8	4.5
3.0	4.05
3.2	3.55
3.4	3.2
3.6	3.05
3.8	2.6
4.0	2.5

CURVE 2*,‡

T	α
1.6	4.0
1.7	5.15
1.8	6.3
1.9	7.5
2.0	9.1
2.1	10.5
2.15	13.0
2.20	16.2
2.25	19.0
2.275	24.0
2.35	7.6
2.4	7.0
2.5	5.9
2.6	5.4
2.8	4.5
3.0	4.05
3.2	3.55
3.4	3.2
3.6	3.05
3.8	2.6
4.0	2.5

CURVE 3*,‡

T	α
1.6	-0.9
1.7	-1.1
1.8	-1.3
1.9	-1.6
2.0	-1.8
2.1	-2.0
2.15	-2.1
2.20	-2.25
2.275	-3.6
2.35	-3.54
2.4	-3.5
2.5	-3.5
2.6	-3.3
2.8	-3.0
3.0	-2.6
3.2	-2.25
3.4	-2.0
3.6	-1.7
3.8	-1.5
4.0	-1.25

CURVE 4*,‡

T	α
1.6	1.5
1.7	1.9
1.8	2.25
1.9	2.7
2.0	3.46
2.1	4.9
2.15	5.4
2.20	6.8
2.25	10.3
2.35	0.0
2.4	-1.3
2.5	-1.5
2.6	-1.6
2.8	-1.8
3.0	-1.75
3.2	-1.5
3.4	-1.3
3.6	-1.1
3.8	-0.95
4.0	-0.8

CURVE 5*,‡

T	α
1.6	3.0
1.7	4.05
1.8	5.3
1.9	6.8
2.0	8.65
2.1	11.6
2.15	15.1
2.20	19.6
2.35	4.8
2.40	4.45
2.50	3.9
2.60	3.5
2.80	2.95
3.00	2.5
3.20	2.2
3.40	1.95
3.60	1.85
3.80	1.7
4.00	1.55

CURVE 12*,‡

T	α
0.50	-2.0
0.91	-5.6
1.11	-8.2
1.27	-10.2
1.35	-12.1
1.44	-15.0
1.52	-17.9
1.56	-21.2
1.60	-25.1
1.61	-28.6
1.62	-38.5
1.62	-9.7
1.63	-7.4
1.66	-5.1
1.73	-2.2
1.80	-2.3
2.02	-1.2
2.55	-0.8
4.00	0.00

CURVE 13*,‡

T	α
0.5	3.6
0.75	7.5

CURVE 13 (cont.)*,‡

T	α
0.90	10.6
1.01	13.4
1.11	15.7
1.20	18.3
1.29	21.3
1.37	24.5
1.44	27.7
1.50	31.5
1.54	35.7
1.57	41.5
1.60	48.0
1.61	69.1
1.61	80.0
1.63	23.7
1.63	18.7
1.65	15.0
1.66	11.7
1.69	8.9
1.75	6.7
1.85	4.9
1.95	3.9
2.07	2.8
2.22	2.4
2.84	1.3
4.00	0.7

CURVE 14*,‡

T	α
0.50	1.1
0.93	3.0
1.32	5.2
1.44	6.2
1.52	7.6
1.59	9.7
1.61	12.4
1.61	14.9
1.61	4.7
1.67	2.8
1.74	1.5
2.55	0.7
4.00	0.4

CURVE 15*,‡

T	α
0.5	-2.2
0.6	-3.1

CURVE 15 (cont.)*,‡

T	α
0.7	-4.0
0.8	-4.9
0.9	-5.9
1.0	-6.9
1.1	-8.1
1.2	-9.4
1.3	-11.1
1.4	-13.5
1.8	-2.37
1.9	-1.75
2.0	-1.35
2.1	-1.10
2.2	-0.92
2.3	-0.77
2.4	-0.67
2.5	-0.57
2.6	-0.50
2.7	-0.45
2.8	-0.40
2.9	-0.35
3.0	-0.32
3.1	-0.30
3.2	-0.25
3.3	-0.22
3.4	-0.20
3.5	-0.17
3.6	-0.17
3.7	-0.15
3.8	-0.15
3.9	-0.10
4.0	-0.10

CURVE 16*,‡

T	α
0.5	3.8
0.6	5.4
0.7	7.1
0.8	8.7
0.9	10.6
1.0	12.6
1.1	14.9
1.2	17.5
1.3	20.9
1.4	25.3
1.8	5.6
1.9	4.2

CURVE 16 (cont.)*,‡

T	α
2.0	3.3
2.1	2.8
2.2	2.4
2.3	2.2
2.4	1.9
2.5	1.7
2.6	1.6
2.7	1.4
2.8	1.3
2.9	1.2
3.0	1.1
3.1	1.0
3.2	0.9
3.3	0.9
3.4	0.8
3.5	0.7
3.6	0.7
3.7	0.7
3.8	0.7
3.9	0.6
4.0	0.6
4.1	0.6
4.2	0.6

CURVE 17*,‡

T	α
0.5	1.10
0.6	1.50
0.7	1.90
0.8	2.30
0.9	2.80
1.0	3.30
1.1	3.80
1.2	4.40
1.3	5.00
1.4	5.80
1.8	1.27
1.9	0.97
2.0	0.77
2.1	0.65
2.2	0.55
2.3	0.47
2.4	0.42
2.5	0.37
2.6	0.35
2.7	0.30

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 280. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS CHLORIDES (continued)

T	α
CURVE 17 (cont.)*,‡	
2.8	0.27
2.9	0.25
3.0	0.22
3.1	0.20
3.2	0.20
3.3	0.17
3.4	0.15
3.5	0.15
3.6	0.12
3.7	0.12
3.8	0.10
3.9	0.10
4.0	0.10
CURVE 18*,‡	
0.55	1.440
0.60	1.540
0.65	1.650
0.70	1.800
0.75	2.110
0.80	2.260
0.85	2.680
0.90	2.980
0.95	3.190
1.00	3.550
1.05	3.760
1.10	4.060
1.15	4.260
1.20	4.520
1.25	4.840
1.30	5.350
1.35	5.920
1.40	6.480
1.45	6.950
1.75	1.592
1.80	1.284
1.85	1.182
1.90	1.106
1.95	1.028
2.00	0.976
2.10	0.863
2.20	0.701
2.30	0.573
2.40	0.491
2.50	0.441
2.60	0.421
2.70	0.393

T	α
CURVE 18 (cont.)*,‡	
2.80	0.365
2.90	0.339
3.00	0.298
3.10	0.267
3.20	0.236
3.30	0.211
3.40	0.203
3.50	0.198
3.60	0.190
3.70	0.190
3.80	0.182
3.90	0.180
CURVE 19*,‡	
0.70	1.90
0.75	2.31
0.80	2.57
0.85	2.82
0.90	3.08
0.95	3.28
1.00	3.65
1.05	3.80
1.10	4.01
CURVE 20*,‡	
1.150	4.42
1.200	4.57
1.250	4.88
1.300	5.14
1.350	5.45
1.400	5.86
1.450	6.42
1.500	7.45
1.510	7.48
1.520	7.64
1.530	7.69
1.540	7.99
1.550	8.12
1.552	9.40
1.558	8.60
1.564	11.00
1.577	12.80
1.583	8.60
1.589	7.30
1.595	14.10
1.600	12.80

T	α
CURVE 20 (cont.)*,‡	
1.606	11.20
1.613	16.40
1.616	16.40
1.626	1.51
1.642	3.12
1.656	2.39
1.673	2.05
1.680	1.93
1.690	1.93
1.700	1.80
1.710	1.80
1.720	1.72
1.730	1.72
1.740	1.69
CURVE 21*,‡	
1.6002	9.40
1.6041	9.50
1.6067	13.40
1.6083	2.57
1.6092	8.56
1.6113	10.40
1.6132	10.6
1.6141	11.0
CURVE 22*,‡	
1.6006	12.8
1.6045	4.67
1.6074	11.80
1.6100	10.10
1.6126	12.30
1.6147	12.20
1.6166	4.82
1.6178	7.34
1.6184	12.8
1.6189	6.43
1.6192	12.8
1.6197	0.00
1.6203	0.00
1.6209	5.14
1.6219	5.14
1.6236	1.51
1.6255	2.34
1.6283	3.89
1.6315	2.49
1.6355	3.08

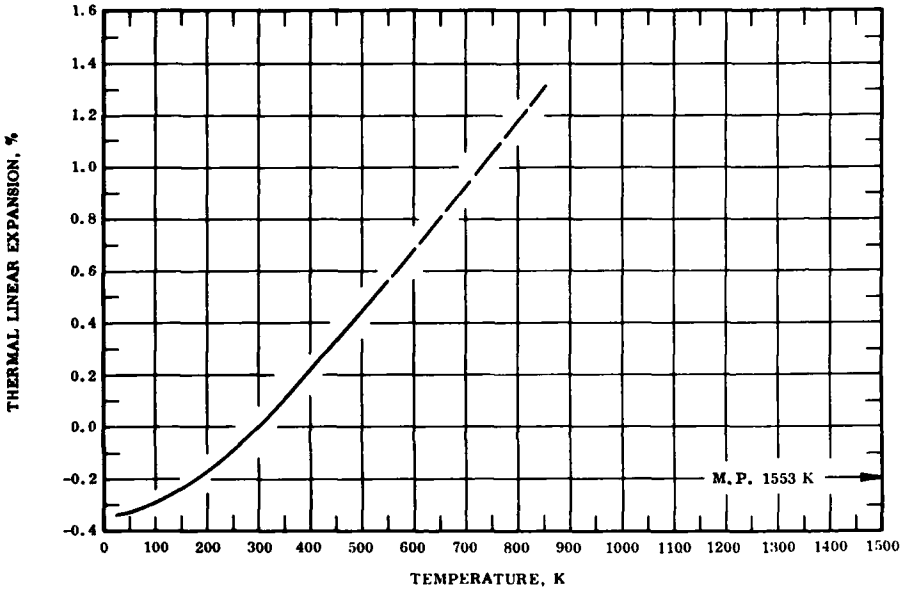
T	α
CURVE 23*,‡	
1.6023	11.9
1.6049	8.9
1.6072	9.4
1.6095	15.0
1.6118	12.3
1.6144	16.2
1.6165	12.8
1.6176	7.0
1.6175	10.6
1.6179	12.8
1.6184	12.8
1.6186	25.7
1.6190	11.4
1.6208	3.4
1.6210	7.1
1.6218	4.5
1.6226	6.1
1.6232	4.5
1.6241	0.0
1.6249	21.4
1.6257	3.9
1.6270	6.1
1.6284	4.5
1.6293	3.3
1.6310	2.2
1.6323	6.2
1.6338	2.3
1.6353	2.5
CURVE 24*,‡	
0.5000	-2.40
0.5500	-2.40
0.6000	-2.48
0.6500	-2.77
0.7000	-3.13
0.7500	-3.42
0.8000	-3.60
0.8500	-4.04
0.9000	-4.40
0.9500	-4.77
1.0000	-5.24
1.0500	-5.68
1.1000	-6.18
1.1500	-6.22
1.2000	-6.92
1.2500	-7.46
1.3000	-7.92

T	α
CURVE 24 (cont.)*,‡	
1.3500	-8.42
1.4000	-9.70
1.4500	-11.60
1.4600	-12.60
1.4700	-13.5
1.4800	-13.70
1.4900	-14.00
1.5000	-13.9
1.5100	-13.70
1.5200	-14.00
1.5300	-14.20
1.5400	-14.3
1.5500	-13.6
1.5600	-14.80
1.5700	-14.7
1.5800	-15.50
1.5900	-17.50
1.6000	-19.30
1.6100	-22.90
1.6160	-24.5
1.6170	-25.00
1.6180	-26.20
1.6190	-28.00
1.6200	-30.20
1.6204	-29.50
1.6208	-33.30
1.6212	-33.20
1.6216	-35.400
1.6220	-16.5
1.6223	-16.8
1.6226	-14.3
1.6231	-13.2
1.6236	-7.750
1.6240	-12.300
1.6244	-9.580
1.6248	-10.300
1.6250	-9.820
1.6260	-8.190
1.6270	-7.650
1.6280	-7.100
1.6290	-6.740
1.6300	-6.360
1.6310	-6.000
1.6320	-5.460
1.6400	-4.720
1.6500	-4.320
1.6600	-3.850
1.6700	-3.000

T	α
CURVE 24 (cont.)*,‡	
1.6800	-3.200
1.6900	-3.000
1.7000	-2.790
1.7200	-2.460
1.7400	-2.250
1.7600	-2.090
1.7800	-1.930
1.8000	-1.680
1.8200	-1.490
1.9000	-1.290
2.0000	-1.050
2.1000	-0.846
2.2000	-0.700
2.3000	-0.564
2.4000	-0.491
2.5000	-0.418
2.6000	-0.373
2.7000	-0.337
2.8000	-0.291
2.9000	-0.264
3.0000	-0.246
3.1000	-0.218
3.2000	-0.200
3.3000	-0.184
3.4000	-0.184
3.5000	-0.164
CURVE 28*,‡	
223	55.0
233	56.0
253	56.0
273	55.0
293	51.0
313	48.0
333	49.0
353	51.0
373	53.0
393	56.0
413	57.0
433	58.0
453	59.0
473	59.0

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 281R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF BARIUM FLUORIDE BaF_2



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
25	-0.330	0.2
50	-0.333	3.4
75	-0.319	6.7
100	-0.298	9.5
150	-0.240	13.6
200	-0.165	16.0
250	-0.080	18.3
293	0.000	19.8
300	0.016	19.9
350	0.123	21.3
400	0.233	22.3
450	0.346	23.1
500	0.461	24.7
550	0.578	24.3†
600	0.698†	24.6†
650	0.819†	24.9†
700	0.942†	25.1†
750	1.066†	25.2†
800	1.190†	25.7†
850	1.316†	25.8†

† Provisional values.

REMARKS

The recommended values are based on the data for pure samples and are considered accurate to within ±5% at temperatures below 550 K and ±7% above 550 K. These values are represented approximately by the following equations:

$$\Delta L/L_0 = -0.339 - 1.960 \times 10^{-4} T + 6.880 \times 10^{-6} T^2 - 7.752 \times 10^{-9} T^3 \quad (25\text{-}293\ K)$$

$$\Delta L/L_0 = -0.549 + 1.627 \times 10^{-3} T + 9.561 \times 10^{-7} T^2 - 3.402 \times 10^{-10} T^3 \quad (293\text{-}850\ K)$$

The tabulated values for the coefficient of thermal expansion at temperatures below 250 K are based on the experimental data and above 250 K the values are derived primarily by differentiating the above equation. The tabulated values are considered accurate to about ±10%.

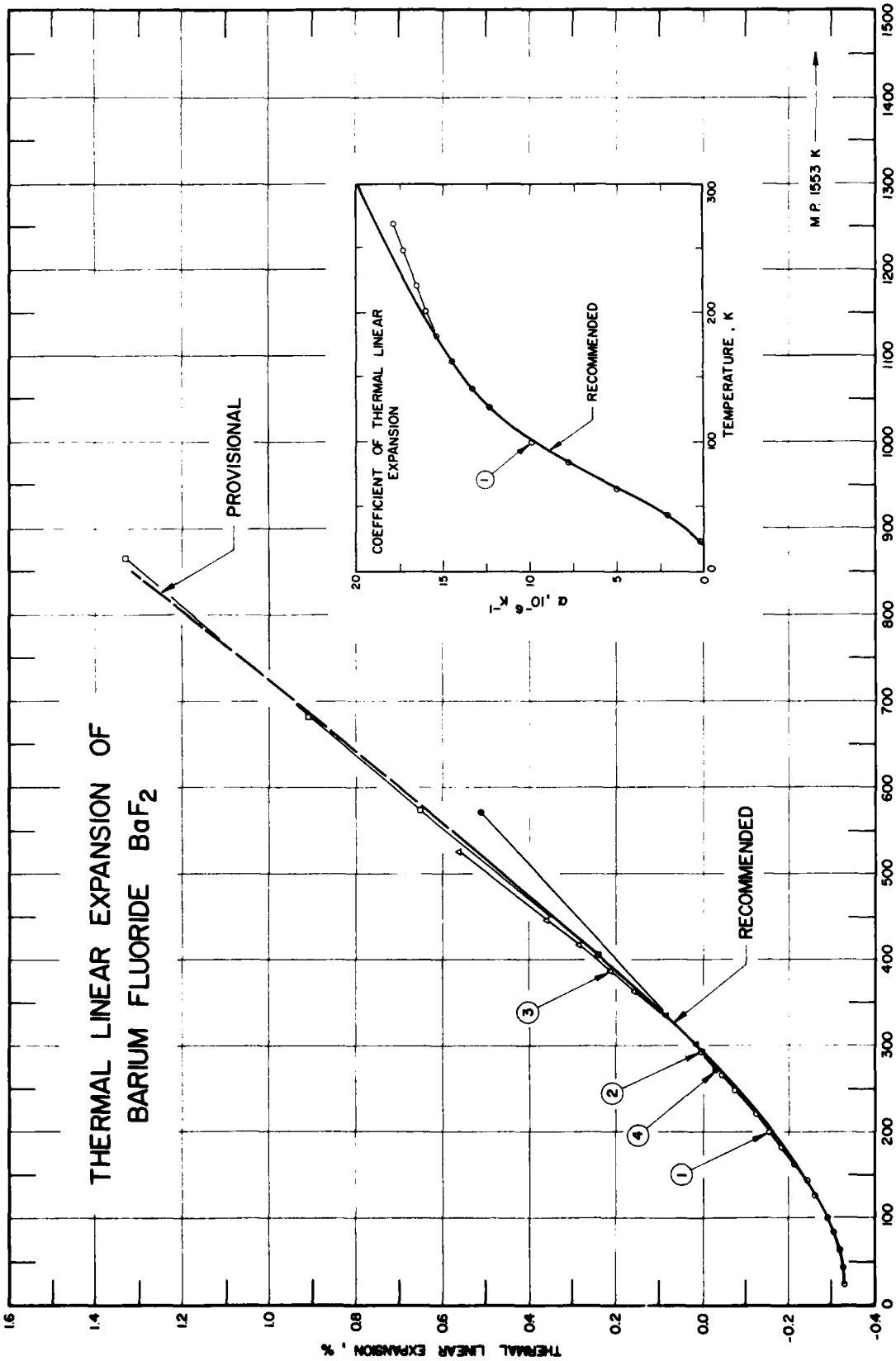

THERMAL LINEAR EXPANSION OF
BARIUM FLUORIDE BaF_2
PROVISIONAL
RECOMMENDED
M.P. 1553 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
TEMPERATURE , K
α ,10⁻⁶ K⁻¹

FIGURE 281

SPECIFICATION TABLE 281. THERMAL LINEAR EXPANSION OF BARIUM FLUORIDE BaF_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	323	Bailey, A.C. and Yates, B.	1967	I	24-268		99.0 pure, <1.0 Sr, ~5.0 excess Ba; single crystal cut to hollow cylinder 1.8 cm I.D., 2.7 cm O.D., 1.0 cm long; obtained from Harshaw Chemicals, Ltd.
2	139	Ferguson, I.F., Street, R.S., and D'Eye, R.W.M.	1960	X	293-866		Specimen precipitated from $BaNO_3$ solution by aqueous HF acid; product washed with aqueous NH_4F, dried at 383 K after adding solid NH_4F, heated to 1173 K in argon to give well-crystallized specimen; lattice parameter reported at 293 K as 6.198± Å.
3	325	Sirdeshmukh, D.B. and Deshpande, V.T.	1964	X	301-527		Lattice parameter reported at 301 K as 6.1940 Å; 6.1930 Å at 293 K determined by graphical extrapolation; coefficient of thermal linear expansion also reported.
4	665	Johnson, R.W.	1967		273-573		No details given.

DATA TABLE 281. THERMAL LINEAR EXPANSION OF BARIUM FLUORIDE BaF_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 2		CURVE 4	
24	-0.331	118	-0.275*	293	0.00	273	-0.037
27	-0.331*	127	-0.264	406	0.24	293	0.000*
33	-0.330*	137	-0.251*	575	0.65	573	0.515
35	-0.330*	142	-0.245	681	0.91		
43	-0.329	152	-0.231*	866	1.33		
53	-0.326*	162	-0.217				
63	-0.322	171	-0.204*	CURVE 3			
64	-0.321*	182	-0.187				
74	-0.315*	190	-0.175*	301	0.016		
83	-0.309	201	-0.158	334	0.082		
86	-0.307*	210	-0.143*	364	0.156		
92	-0.302*	221	-0.125	387	0.209		
94	-0.300*	231	-0.108*	419	0.282		
100	-0.294	249	-0.078	446	0.359		
103	-0.291*	257	-0.064*	527	0.560		
108	-0.286*	268	-0.044				

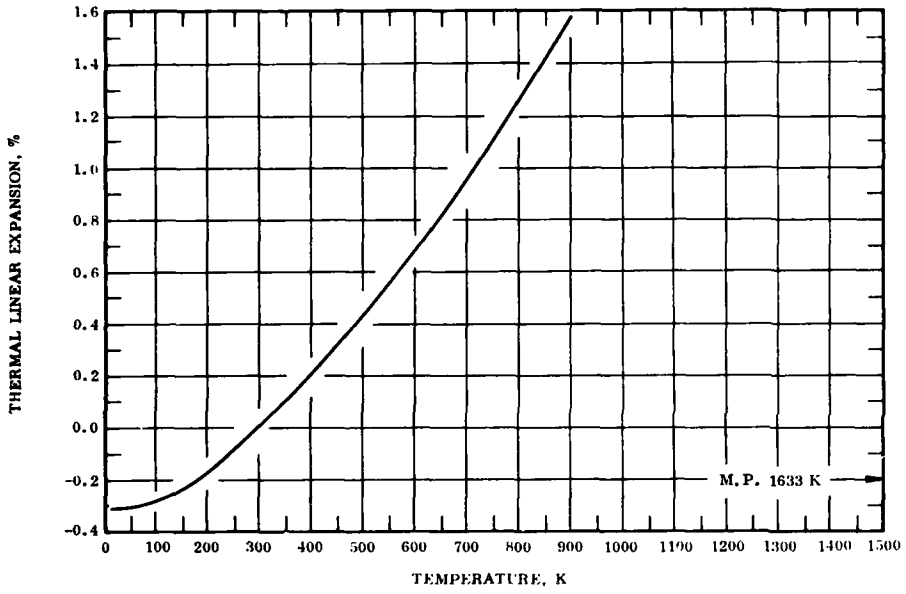
DATA TABLE 281. COEFFICIENT OF THERMAL LINEAR EXPANSION OF BARIUM FLUORIDE BaF_2

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 3*	
24	0.2	127	12.3	313	20.4
27	0.6	137	13.0	353	22.0
33	1.0	142	13.3	393	23.2
35	1.2	152	13.9	433	24.4
43	2.1	162	14.4	473	25.7
53	3.5	171	14.8	513	26.8
63	4.9	182	15.4		
64	5.3	190	15.6		
74	6.6	201	15.9		
83	7.7	210	16.3		
86	7.9	221	16.5		
92	9.1	231	16.8		
94	9.2	249	17.3		
100	9.8	257	17.6		
103	10.0	268	17.8		
108	10.7				
118	11.6				

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 282R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF CALCIUM FLUORIDE CaF_2



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
5	-0.313	0.01
10	-0.313	0.03
25	-0.313	0.15
50	-0.312	1.8
75	-0.303	4.8
100	-0.287	7.7
150	-0.236	12.5
200	-0.165	15.8
250	-0.080	17.8
293	0.000	19.1
300	0.013	19.2
350	0.112	20.2
400	0.214	20.9
450	0.320	21.6
500	0.431	22.6
550	0.547	23.8
600	0.670	25.1
650	0.799	26.7
700	0.937	28.4
750	1.083	30.3
800	1.240	32.3
850	1.406	34.4
900	1.585	36.6

REMARKS

The recommended values are based on the data for high purity powdered sample (curves 4, 7, 8, and 9) and hot-pressed sample (curve 6) commonly known as Irtran 3. These values are considered accurate to within ± 5% and are represented approximately by the following equations:

$$\Delta L/L_0 = -0.305 - 5.109 \times 10^{-4}\, T + 7.739 \times 10^{-6}\, T^2 - 8.345 \times 10^{-9}\, T^3 \quad (25\text{-}293\ K)$$

$$\Delta L/L_0 = -0.564 + 1.991 \times 10^{-3}\, T - 5.582 \times 10^{-7}\, T^2 + 1.109 \times 10^{-9}\, T^3 \quad (293\text{-}900\ K)$$

The tabulated values for the coefficient of thermal expansion are derived from the experimental data and are considered accurate to about ± 10%.

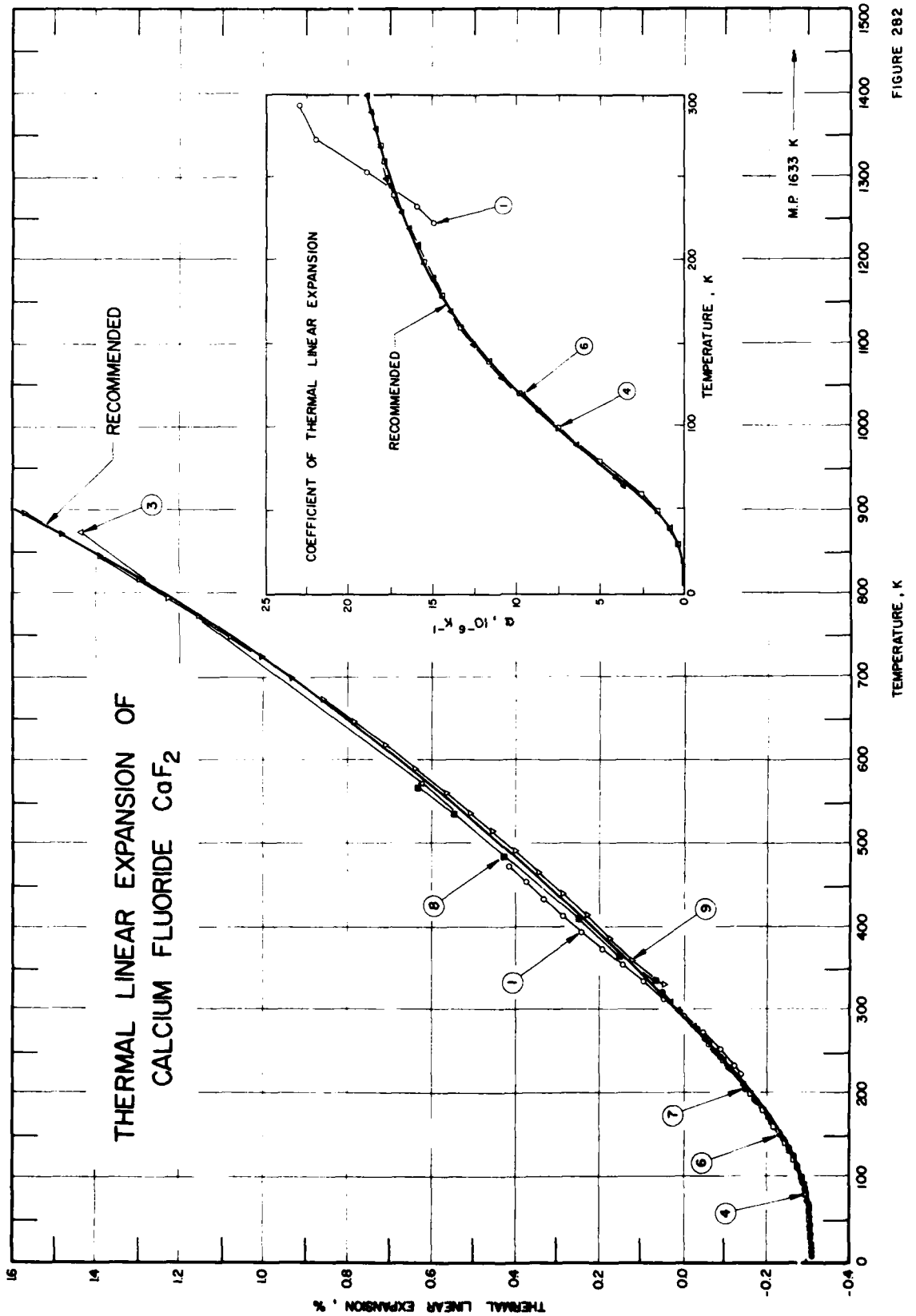

THERMAL LINEAR EXPANSION OF
CALCIUM FLUORIDE CaF_2
RECOMMENDED
M.P. 1633 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
α , 10^{-6} K^{-1}
TEMPERATURE , K

FIGURE 282

SPECIFICATION TABLE 282. THERMAL LINEAR EXPANSION OF CALCIUM FLUORIDE CaF_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	322	Combes, L.S., Ballard, S.S., and McCarthy, K.A.	1951	L	223-473		Sample furnished by the Harshaw Chemical Co. of Cleveland, Ohio; bar specimen; expansion measurements made in Carpenter Steel Co., Reading, Pennsylvania.
2*	322	Combes, L.S., et al.	1951	L	223-473		The above specimen; average values.
3	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	298-1173		Specimen with a cross section 1.3 x 1.3 and 17.8 cm long; the ends sawed at a rake and to a point; sintered high density.
4	323	Bailey, A.C. and Yates, B.	1967	I	30-270		>99.98 pure; specimen obtained from Koch-Light Laboratories; single crystal cut to hollow cylinder 1.8 cm I.D., 2.7 cm O.D., 1 cm long.
5*	148	Ballard, S.S. and Browder, J.S.	1966	I	273-333	Irtran 3	Infrared-transmitting optical material; microcrystalline; hot-pressed compact developed by the Eastman Kodak Co. of New York; high transmittance uncoated; at 298 K transmittance < 0.4 to 11.5 μ; better than single crystal in thermal shocks resistance; density 3.18 g cm^{-3}; reported error < 2.0%.
6	149	Browder, J.S. and Ballard, S.S.	1969	E	65-310	Irtran 3	Microcrystalline; hot-pressed compact developed by the Eastman Kodak Co. of Rochester, N.Y.
7	324	Batchelder, D.N. and Simmons, R.O.	1964	X	6-320		Specimen obtained from Optovac, Inc.; <111> oriented crystal disc 1 mm thick x 12 mm diameter cleaved from crystalline rod; clamped and glued at one edge to copper block on cryostat; authors reported the thermal lattice expansivity; zero-point correction of -0.03750% determined by graphical interpolation.
8	325	Sirdeskmukh, D.B. and Desphande, V.T.	1964	X	299-569		Lattice constant reported at 299.2 K as 5.4640 ± 0.0002 Å; 5.4633 Å at 293 K determined by graphical extrapolation; coefficient of thermal expansion also reported from 313-553 K.
9	121	Sharma, S.S.	1950	I	331-923	Fluorite	Fluorite crystal was clear, transparent, colorless piece in the form of triangular prism; three pieces cut parallel to the natural cleavage plane and turned into the required pyramidal shape; initial length at 273 K, 0.2992 cm; zero-point correction of 0.0090% determined by graphical extrapolation; coefficient of thermal expansion also reported.

*Not shown in figure.

DATA TABLE 282. THERMAL LINEAR EXPANSION OF CALCIUM FLUORIDE CaF_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
223	-0.136
233	-0.121
253	-0.086
273	-0.045
293	0.000
313	0.048
333	0.098
353	0.147
373	0.195
393	0.243
413	0.290
433	0.335
453	0.378
473	0.418
CURVE 2*	
223	-0.133
293	0.000
373	0.192
473	0.414
CURVE 3	
298	0.011
573	0.624
873	1.438
1173	2.297*
CURVE 4‡	
30	-0.307
40	-0.306
50	-0.305
60	-0.303
80	-0.295
100	-0.283
120	-0.265
140	-0.244
160	-0.219
180	-0.191
200	-0.161
220	-0.129*
240	-0.095
260	-0.060
270	-0.042*

T	$\Delta L/L_0$
CURVE 5*	
273	-0.039
298	0.009
333	0.079
CURVE 6‡	
65	-0.302
70	-0.300
80	-0.296*
90	-0.290
100	-0.283*
110	-0.275
120	-0.265
130	-0.255
140	-0.244
150	-0.232
160	-0.219
170	-0.205
180	-0.191
190	-0.176
200	-0.161
210	-0.145
220	-0.129
230	-0.112
240	-0.095
250	-0.078
260	-0.060
270	-0.042
280	-0.024
290	-0.006
300	0.013
310	0.032
CURVE 7	
6.4	-0.308
6.4	-0.308*
7.4	-0.308
8.2	-0.307*
9.6	-0.307*
12.57	-0.308
13.14	-0.308*
16.63	-0.308
17.53	-0.307*
21.44	-0.308
23.64	-0.308*

T	$\Delta L/L_0$
CURVE 7 (cont.)	
26.94	-0.307
28.54	-0.308*
32.18	-0.308*
34.05	-0.308
37.33	-0.308
38.06	-0.308*
41.95	-0.307*
44.73	-0.307
44.76	-0.306*
47.69	-0.306*
49.52	-0.306*
53.73	-0.305
55.42	-0.304*
57.75	-0.305
60.20	-0.304*
63.35	-0.304*
64.88	-0.301*
67.74	-0.301*
69.96	-0.301*
72.96	-0.299
77.91	-0.297*
81.35	-0.295*
87.64	-0.292
92.79	-0.289*
96.89	-0.285
101.22	-0.283*
108.31	-0.278*
114.34	-0.272
119.17	-0.268*
123.86	-0.263
128.36	-0.258*
135.22	-0.250
144.25	-0.240
152.24	-0.230*
158.37	-0.222
165.32	-0.213
171.63	-0.204*
180.62	-0.190*
194.18	-0.171
209.62	-0.147
229.40	-0.113
229.90	-0.113*
239.21	-0.097*
244.87	-0.088
251.57	-0.076*
259.61	-0.062*

T	$\Delta L/L_0$
CURVE 7 (cont.)	
266.86	-0.048
276.34	-0.032
280.89	-0.023*
288.48	-0.008*
296.36	0.005*
300.88	0.015*
308.36	0.029
316.13	0.043
321.93	0.053
CURVE 8	
299	0.012*
335	0.073
365	0.153
410	0.250
484	0.428
537	0.549
569	0.635
CURVE 9	
330.9	0.047
359.6	0.122
387.7	0.178
414.8	0.234
440.7	0.290
466.1	0.346
491.0	0.401
515.2	0.457
538.6	0.512
561.8	0.567
591.1	0.641
619.7	0.715
647.3	0.788
673.8	0.861
699.5	0.935
724.8	1.008
749.4	1.082
773.0	1.155
796.0	1.228
818.5	1.302
846.0	1.393
872.6	1.485
898.0	1.576
922.9	1.668

*Not shown in figure.

‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 282. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CALCIUM FLUORIDE CaF_2

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
223	15
233	16
253	19
273	22
293	23
313	25*
333	25*
353	24*
373	24*
393	24*
413	23*
433	22*
453	21*
473	19*
CURVE 4‡	
30	0.3
40	0.8
50	1.6
60	2.6
80	5.1
100	7.6
120	9.9
140	11.7
160	13.3
180	14.5
200	15.6
220	16.5
240	17.3
260	17.9
270	18.2
CURVE 6‡	
65	3.60
70	4.10
80	5.11
90	6.35
100	7.60
110	8.81
120	9.89
130	10.9
140	11.7
150	12.6
160	13.3
170	13.9
180	14.5
190	15.0
200	15.5
210	15.9
220	16.3
230	16.8
240	17.2
250	17.5
260	17.8
270	18.1
280	18.4
290	18.7
300	18.9
310	19.1*
CURVE 8*	
313	20.7
353	21.6
393	22.1
433	23.2
473	23.6
513	24.7
553	24.7
CURVE 9*	
316.2	19.36
345.3	19.69
373.7	20.00
401.3	20.65
427.8	21.54
453.4	21.92
478.6	22.31
503.1	22.92
526.9	23.66
550.0	24.37
576.2	24.73
605.4	25.72
633.5	26.64
660.6	27.71
686.7	28.59
712.2	29.00
737.1	29.80
761.2	31.07
784.5	31.86
807.3	32.56
832.2	33.30
859.3	34.42
885.3	36.03
910.5	36.75

*Not shown in figure.

‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

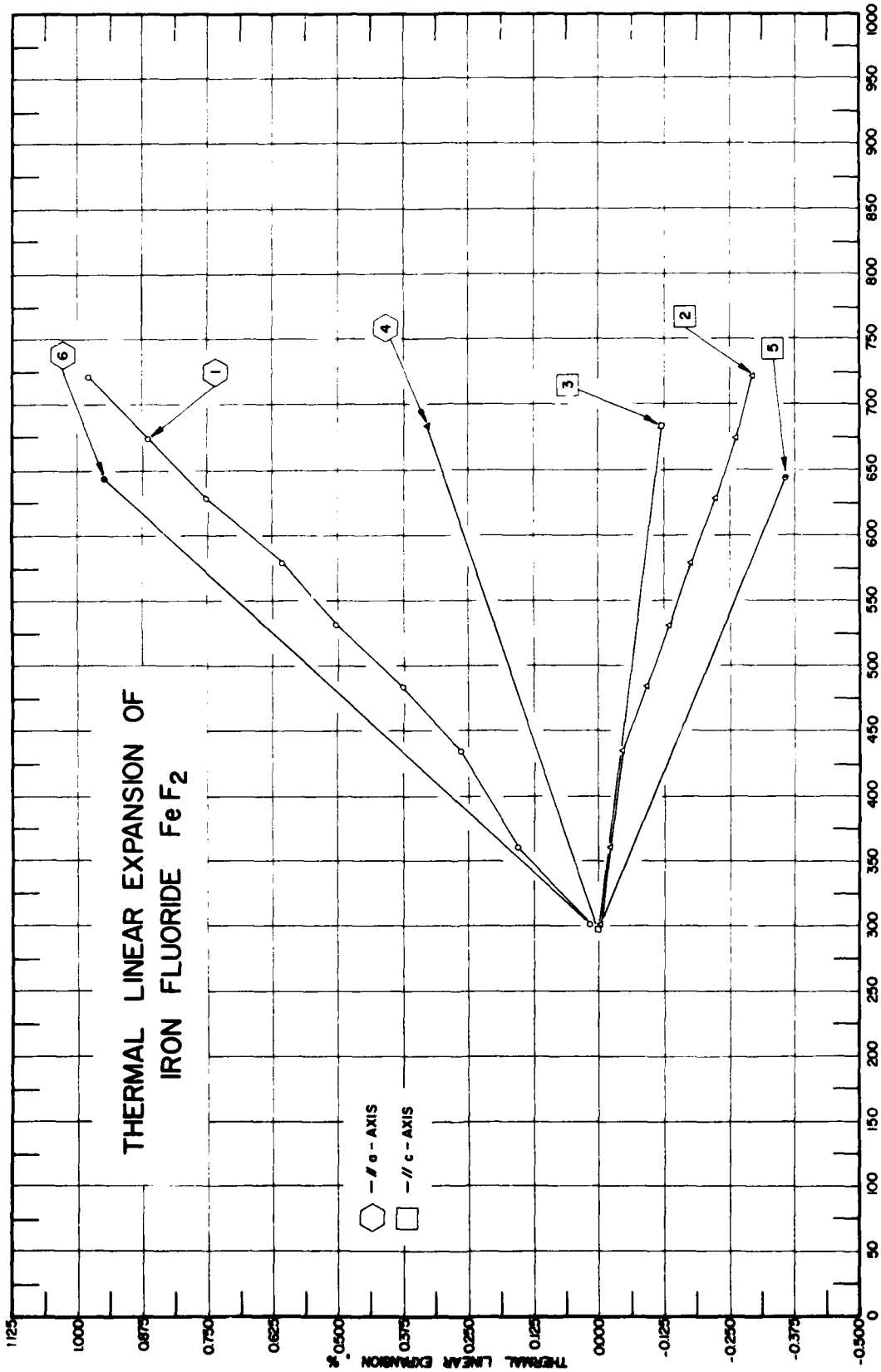

THERMAL LINEAR EXPANSION OF
IRON FLUORIDE FeF_2
— // a - AXIS
— // c - AXIS
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.125
1.000
0.875
0.750
0.625
0.500
0.375
0.250
0.125
0.000
-0.125
-0.250
-0.375
-0.500
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1
2
3
4
5
6

FIGURE 283

SPECIFICATION TABLE 283. THERMAL LINEAR EXPANSION OF IRON DIFLUORIDE FeF_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	784	Rao, K. V. K., Naidu, S. V. N., and Iyengar, L.	1966	X	301-722		Specimen obtained from Prof. Stout of University of Chicago; expansion measured along a-axis; lattice parameter reported at 307 as 4.6945 Å; 4.6936 Å at 293 K determined by graphical extrapolation.
2	784	Rao, K. V. K., et al.	1966	X	301-722		The above specimen; expansion measured along c-axis; lattice parameter reported at 301 K as 3.3097 Å; 3.30978 Å at 293 K determined by graphical extrapolation.
3	783	Rao, K. V. K.	1974	X	298, 683		Expansion measured along c-axis.
4	783	Rao, K. V. K.	1974	X	298, 683		Expansion measured along a-axis.
5	140	Rao, K. V. K. and Iyengar, L.	1968	X	303, 643		Specimen prepared by crushing to powder form and coating powder with Araldite on to a quartz fiber; expansion measured along c-axis.
6	140	Rao, K. V. K. and Iyengar, L.	1968	X	303, 643		The above specimen; expansion measured along a-axis.

DATA TABLE 283. THERMAL LINEAR EXPANSION OF IRON DIFLUORIDE FeF_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
301	0.0185
360	0.155
434	0.264
483	0.376
531	0.504
579	0.607
627	0.751
674	0.869
722	0.981
CURVE 2	
301	-0.0025
360	-0.0206
434	-0.0446
CURVE 2 (cont.)	
483	-0.0901
531	-0.132
579	-0.175
627	-0.223
674	-0.262
722	-0.293
CURVE 3	
298	0.000
683	-0.119
CURVE 4	
298	0.008*
683	0.329
CURVE 5	
303	0.000*
643	-0.356
CURVE 6	
303	0.016*
643	0.950

* Not shown in figure.

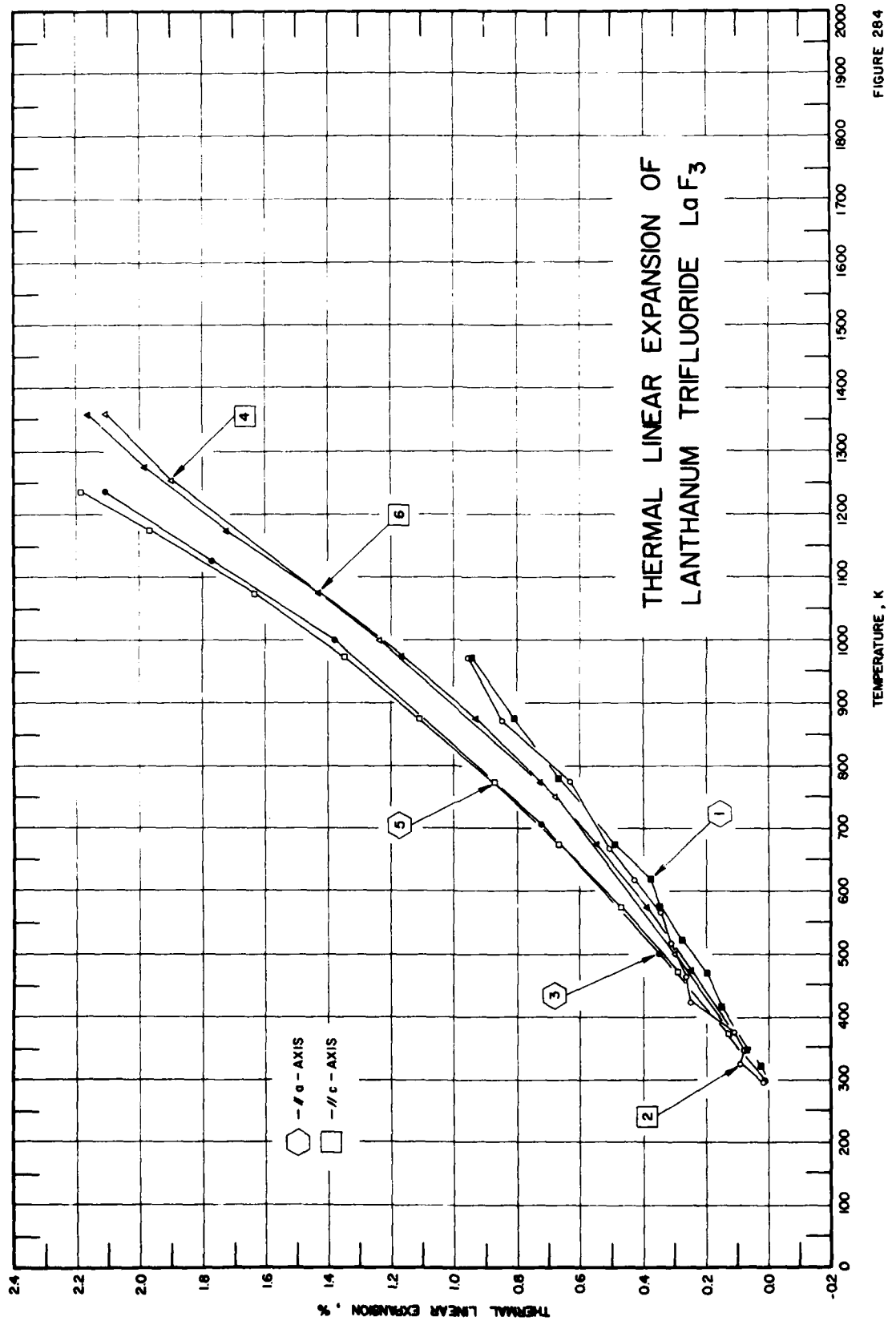

THERMAL LINEAR EXPANSION OF
LANTHANUM TRIFLUORIDE LaF3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
-// a - AXIS
-// c - AXIS
1
2
3
4
5
6

FIGURE 284

SPECIFICATION TABLE 284. THERMAL LINEAR EXPANSION OF LANTHANUM TRIFLUORIDE LaF_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	785, 1025	Sher, A., Solomon, K., Lee, K., and Muller, M.W.	1966, 1965	X	297-970		Polycrystalline specimen; expansion measured in nitrogen atmosphere along a-a-axis; lattice parameter reported at 297 K as 7.185 Å; 7.1848 Å at 293 K determined by graphical extrapolation.
2	785, 1025	Sher, A., et al.	1966, 1965	X	299-970		The above specimen; expansion measured along c-axis; lattice parameter reported at 299 K as 14.697 Å; 14.694 Å at 293 K determined by graphical extrapolation.
3	785, 1025	Sher, A., et al.	1966, 1965	L	300-1235		Single crystal specimen; expansion measured in argon atmosphere along a-axis; zero-point correction -0.012% at 293 K.
4	785, 1025	Sher, A., et al.	1966, 1965	L	300-1359		The above specimen; expansion measured along c-axis; zero-point correction -0.01% at 293 K.
5	1026	Mooney, J.B.	1966	L	302-1231		Single crystal specimen; expansion measured in argon atmosphere along a-axis; zero-point correction -0.014% at 293 K.
6	1026	Mooney, J.B.	1966	L	302-1355		The above specimen; expansion measured along c-axis; zero-point correction -0.012% at 293 K.

DATA TABLE 284. THERMAL LINEAR EXPANSION OF LANTHANUM TRIFLUORIDE LaF_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
297	0.002*
322	0.016
349	0.072*
373	0.114*
420	0.155
472	0.197
521	0.280
574	0.349
620	0.377
672	0.489
779	0.670
873	0.809
970	0.948
CURVE 2	
299	0.019
323	0.094
CURVE 2 (cont.)	
348	0.080
371	0.114
422	0.250
468	0.264
519	0.318
568	0.345
618	0.427
669	0.509
772	0.631
870	0.849
970	0.958
CURVE 3	
300	0.012*
501	0.352
706	0.722
1000	1.380
CURVE 3 (cont.)	
1126	1.770
1235	2.180
CURVE 4	
300	0.010*
500	0.300
750	0.680
1000	1.240
1251	1.900
1359	2.160
CURVE 5	
302	0.014*
373	0.126
473	0.291
573	0.471
CURVE 5 (cont.)	
673	0.669
773	0.875
873	1.111
973	1.344
1073	1.635
1173	1.971
1231	2.195
CURVE 6	
302	0.012*
373	0.110*
473	0.248
573	0.392
673	0.546
773	0.725
873	0.932
973	1.166
CURVE 6 (cont.)	
1073	1.436
1173	1.724
1273	1.989
1355	2.168

* Not shown in figure.

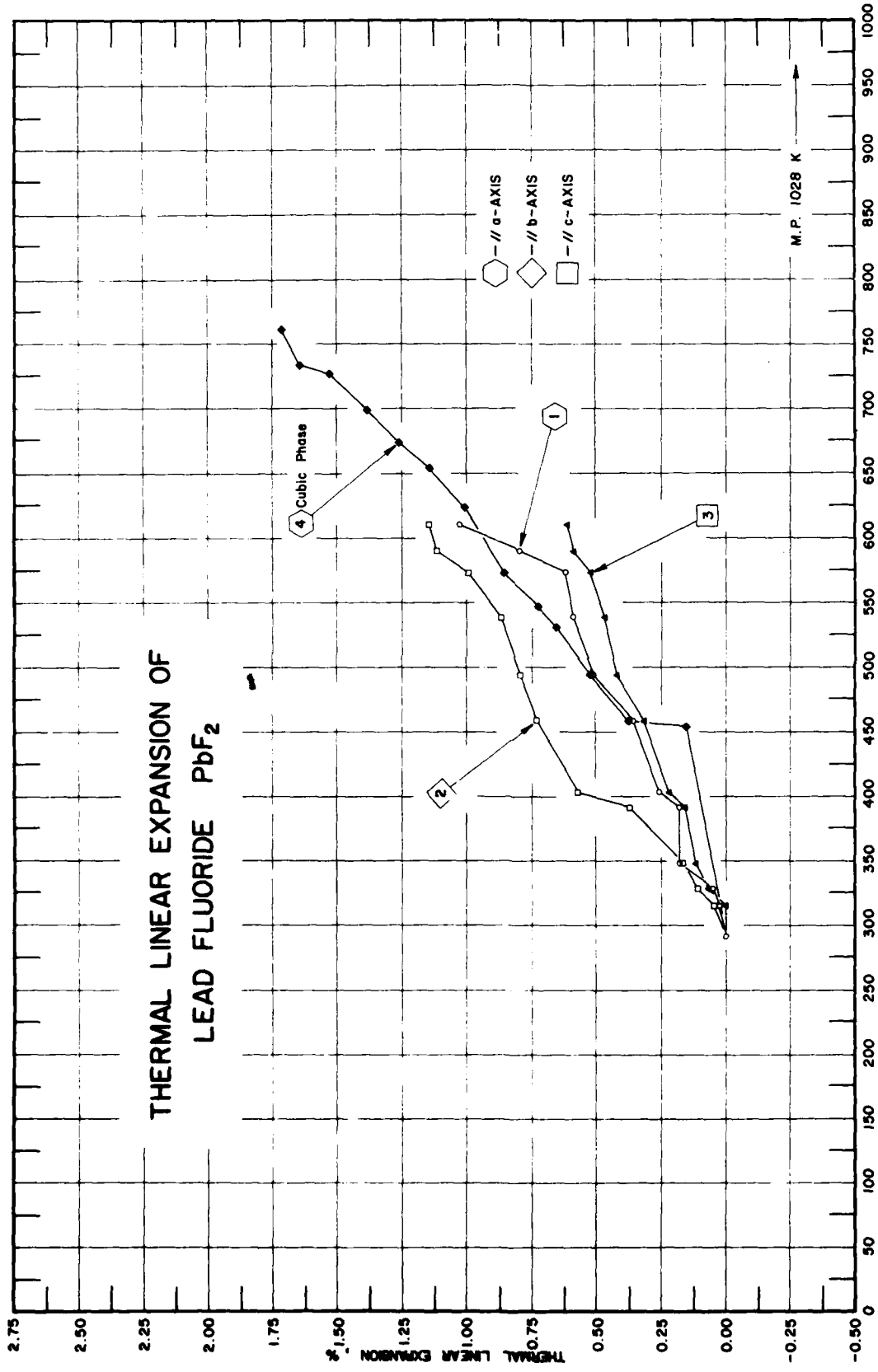


FIGURE 285

THERM. PROP.-V 13 35.

SPECIFICATION TABLE 285. THERMAL LINEAR EXPANSION OF LEAD DIFLUORIDE PbF_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	295	Hsu, Y. T.	1967	X	291-610		Reagent quality orthorhombic structured powder, placed in 0.3 mm diameter capillary; expansion measured along a-axis; expansion determined by average of reported lattice parameter; lattice parameter reported at 291 K as 3.897 Å; 3.897 Å at 293 K determined by graphical interpolation.
2	295	Hsu, Y. T.	1967	X	291-610		The above specimen; expansion measured along b-axis; expansion determined by average of reported lattice parameter; lattice parameter reported at 291 K as 6.446 Å; 6.446 Å at 293 K determined by graphical interpolation.
3	295	Hsu, Y. T.	1967	X	291-610		The above specimen; expansion measured along c-axis; expansion determined by average of reported lattice parameter; lattice parameter reported at 291 K as 7.651 Å; 7.651 Å at 293 K determined by graphical interpolation.
4	295	Hsu, Y. T.	1967	X	291-761		Similar to the above specimen; except cubic structure; expansion measured along a-axis; expansion determined by average of reported lattice parameter; lattice parameter reported at 291 K as 5.951 Å; 5.951 Å at 293 K determined by graphical interpolation.

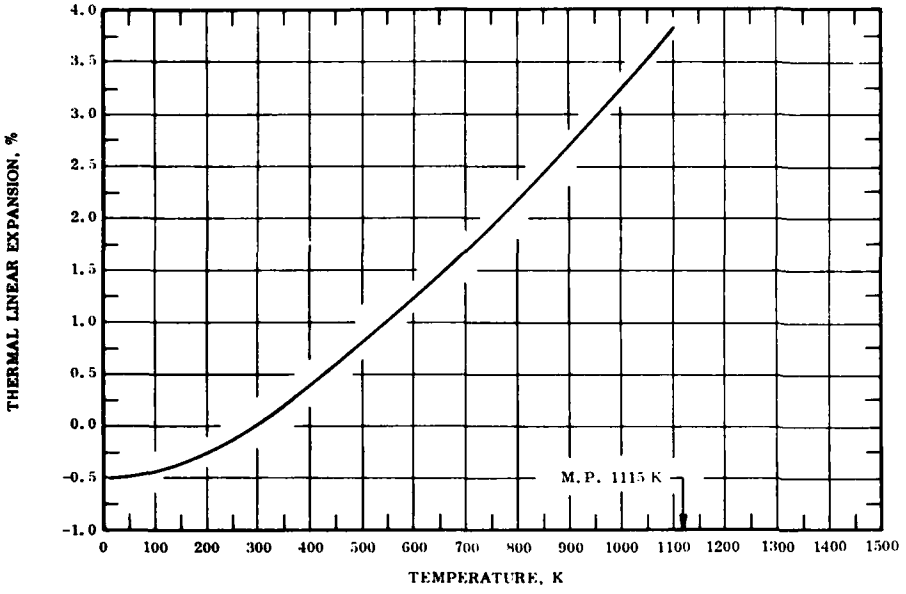
DATA TABLE 285. THERMAL LINEAR EXPANSION OF LEAD DIFLUORIDE PbF_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3		CURVE 4	
291	0.000	291	0.000*	291	0.000*	291	0.000*
315	0.026	315	0.047	315	0.000	454	0.151
328	0.051	328	0.109	328	0.065	458	0.370
348	0.180	348	0.171	348	0.118	493	0.521*
391	0.180	391	0.372	391	0.157	531	0.655
403	0.257	403	0.574	403	0.222	547	0.723
458	0.359	458	0.729	458	0.314	573	0.857
493	0.513	493	0.791	493	0.418	623	1.008
539	0.590	539	0.869	539	0.471	654	1.143
573	0.616	573	0.993	573	0.523	673	1.260
590	0.796	590	1.117	590	0.588	698	1.378
610	1.026	610	1.148	610	0.614	727	1.529
						733	1.647
						761	1.714

* Not shown in figure.

FIGURE AND TABLE NO. 286R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF LITHIUM FLUORIDE LiF



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
10	-0.485	0.2
20	-0.485	0.5
25	-0.485	0.7
50	-0.481	2.2
75	-0.472	5.5
100	-0.453	10.0
150	-0.378	19.6
200	-0.275	26.1
250	-0.140	31.0
293	0.000	33.9
300	0.026	34.4
400	0.405	38.6
500	0.805	41.7
600	1.227	44.0
700	1.678	46.5
800	2.160	49.6
900	2.679	53.0
1000	3.237	58.2
1100	3.839	66.7

REMARKS

The recommended values are based on the data for high purity samples and are considered accurate to within ±5%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -1.035 + 3.424 \times 10^{-3}\, T + 1.733 \times 10^{-7}\, T^2 + 6.745 \times 10^{-10}\, T^3 \quad (293\text{-}1100\ K)$$

The tabulated values for the coefficient of thermal expansion are primarily based on the experimental data and considered accurate to about ±10%.

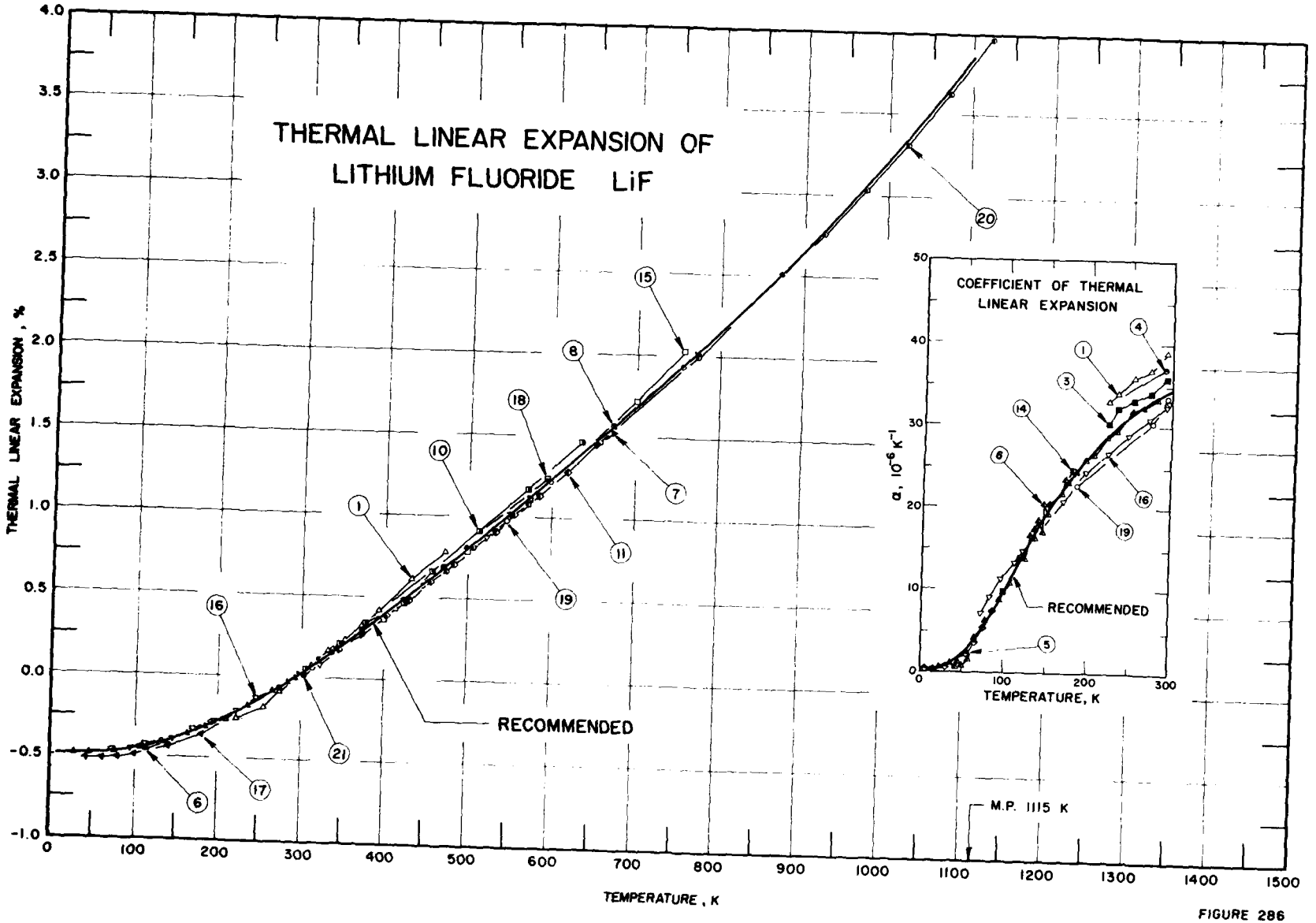

THERMAL LINEAR EXPANSION OF
LITHIUM FLUORIDE LiF
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED
M.P. 1115 K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
α, 10⁻⁶ K⁻¹
TEMPERATURE, K
RECOMMENDED

FIGURE 286

SPECIFICATION TABLE 286. THERMAL LINEAR EXPANSION OF LITHIUM FLUORIDE LiF

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	322	Combes, L.S., Ballard, S.S., and McCarthy, K.A.	1951	L	223-473		Sample furnished by the Harshaw Chemical Co. of Cleveland, Ohio; bar specimen; crystal air grown.
2*	322	Combes, L.S., et al.	1951	L	223-473		The above specimen; average values.
3*	322	Combes, L.S., et al.	1951	L	223-473		Similar to the above specimen except vacuum grown.
4*	322	Combes, L.S., et al.	1951	L	223-473		The above specimen; average values.
5*	479	White, G.K.	1965	C	4-85		Optical quality; cylindrical specimen 2 cm diameter x 5 cm long; obtained from Isomet Corporation of New Jersey; data smoothed by author; this curve is here reported using 4 K as the reference temperature at which $\Delta L/L_0 = 0$.
6	480	Yates, B. and Panter, C.H.	1962	I	26-281		99.99+ pure single crystal; expansion observed with cadmium green light (5085.8 Å); zero-point correction is -0.499% at 293 K.
7	481	McKinstry, H.A.	1960	X	299-774		Single crystal freshly cleaned surface; series of runs in a week, without adjustment of the furnace or sample, a test of the reproducibility of the equipment; good reproducibility; lattice parameter reported at 299.45 K as 4.02630 Å; 4.02541 Å at 293 K determined by graphical extrapolation.
8	481	McKinstry, H.A.	1960	X	300-770		The above specimen; another run; lattice parameter reported at 300.70 K as 4.02502 Å; 4.02381 Å at 293 K determined by graphical extrapolation.
9*	491	McKinstry, H.A.	1960	X	301-761		The above specimen; another run; lattice parameter reported at 300.95 K as 4.02599 Å; 4.02478 Å at 293 K determined by graphical extrapolation.
10	157	Pathak, P.D., Pandya, N.V., and Ghadiali, M.P.	1962	X	306-639		Lattice parameter reported at 306 K as 4.0140 Å; 4.0119 Å at 293 K determined by graphical extrapolation.
11	161	Sharma, S.S.	1950		315-653		Artificially grown, supplied by Harshaw Chemical Co., Ohio; zero-point correction is -0.08% at 293 K.
12*	788	Carrison, L.C. and Sclar, C.B.	1968	X	298-673		Specimen mixed with NaCl for calibration; expansion measured under pressure of 38 kbar; zero-point correction is 0.014% at 293 K.
13*	788	Carrison, L.C. and Sclar, C.B.	1968	X	298-873		Similar to the above specimen; expansion measured under pressure of 57 kbar estimated; zero-point correction is 0.020% at 293 K.
14*	581	Shah, J.S.	1971	X	40-180		Sample prepared by grinding the coarse powder and sieving it through a 10 μ sieve; lattice parameter not corrected for refraction; lattice parameter reported as 4.00517 Å at 40 K; this curve is here reported using the first temperature as the reference temperature at which $\Delta L/L_0 = 0$; coefficient of thermal linear expansion also reported.
15	625	Srivastava, K.K. and Merchant, H.D.	1972	X	293-759		No details given.
16	771	Rapp, J.E. and Merchant, H.D.	1972	L	71-575		Crystal orientation was <1,0,0>; dimensions: 5 x 5 x 13 mm; smoothed data.
17	789	Shah, J.S. and Straumanis, M.E.	1972	X	40-298		Specimen powder was ground and sieved through a 10 μ sieve; results were averaged from three runs; lattice parameter reported at 298 K as 4.02617 Å; 4.02599 Å at 293 K determined by graphical extrapolation.
18	664	Whittemore, D.O.	1962	L	293,593		Reagent grade powder; dimensions: cylindrical 1.27 cm diameter x 2.54 cm long; powder pressed at 277 g cm^{-2} in a steel mold; two such cylinders placed end to end constituted one test sample.

* Not shown in figure.

SPECIFICATION TABLE 286. THERMAL LINEAR EXPANSION OF LITHIUM FLUORIDE LiF (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
19	663	Von Trost, K. F.	1963		133-756		No details given.
20	790	Pathak, P. D. and Vasavada, N. G.	1971	L	273-1123		No details given.
21	791	Murat, M., Chatelut, F., and Bordot, C.	1969	L	293-500		Rectangular bar; pulverized powder pressed at 9427 psi, subjected to thermal cycles of 573 K/hr; zero-point correction is 0.029% at 293 K.
22*	786	Baikov, Y. M., Ryskin, C. Ya., Stepanov, Yu. P., Subashiev, A. V., Korenbilt, I. Ya., and Klochikhin, A. A.	1969		292,313	Li^6F	Dimensions: 2-4 mm crystal; salt prepared from almost pure Li; crystal made by kyropoulous melt method; specimen floated in bromoform + ethylene bromide with expansion measured using pycnometer density 2.5455 g cm^{-3} at 293 K; L^6 concentration in sample is 99.82 at.%.
23*	786	Baikov, Y. M., et al.	1969		292,313	Li^7F	Similar to the above specimen except Li^6 concentration is 0.014 at.% and density is 2.6481 g cm^{-3} at 293 K.

* Not shown in figure.

DATA TABLE 286. THERMAL LINEAR EXPANSION OF LITHIUM FLUORIDE LiF

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
223	-0.251
233	-0.218
253	-0.148
273	-0.075
293	0.000
313	0.077
333	0.157
353	0.241
373	0.328
393	0.417
413	0.508
433	0.601
453	0.697
473	0.797
CURVE 2*	
223	-0.252
293	0.000
373	0.328
473	0.792
CURVE 3*,‡	
223	-0.233
233	-0.202
253	-0.137
273	-0.070
293	0.000
313	0.072
333	0.145
353	0.220
373	0.298
393	0.379
413	0.464
433	0.555
453	0.651
473	0.753
CURVE 4*	
223	-0.231
293	0.000
373	0.296
473	0.756

T	$\Delta L/L_0$
CURVE 5*,‡	
4	0.000×10^{-3}
5	0.001
6	0.003
7	0.004
8	0.006
10	0.009
12	0.009
14	0.005
16	0.000
18	0.008
20	0.019
22	0.034
24	0.053
26	0.079
28	0.113
30	0.115
57.5	3.649
65	5.861
75	10.261
85	16.461
CURVE 6‡	
26	-0.499
32	-0.499*
36	-0.498*
39	-0.498*
43	-0.498
47	-0.497*
50	-0.497*
51	-0.497*
59	-0.496*
60	-0.496*
62	-0.495*
68	-0.493*
69	-0.492*
76	-0.489
79	-0.487*
84	-0.484*
91	-0.480*
95	-0.476*
99	-0.473*
106	-0.466*
113	-0.458
117	-0.453*
123	-0.445*

T	$\Delta L/L_0$
CURVE 6 (cont.)‡	
127	-0.439*
129	-0.436*
131	-0.433*
133	-0.429*
136	-0.424*
140	-0.417
143	-0.412*
144	-0.410*
148	-0.403*
151	-0.397*
154	-0.391*
157	-0.385*
161	-0.376
167	-0.364*
169	-0.359*
172	-0.352*
173	-0.350*
178	-0.339*
185	-0.322
198	-0.289*
201	-0.282*
206	-0.269*
210	-0.258
221	-0.256*
222	-0.223*
233	-0.192*
236	-0.183
252	-0.133*
256	-0.121*
265	-0.092
281	-0.039
CURVE 7	
299.45	0.022
372.95	0.276
373.20	0.276*
672.70	1.53
675.70	1.54*
773.95	2.02
CURVE 8	
300.70	0.030*
374.70	0.314*
474.45	0.697

T	$\Delta L/L_0$
CURVE 8 (cont.)	
573.20	1.120
673.45	1.570
673.95	1.570*
769.70	2.030*
CURVE 9*	
300.95	0.030
473.45	0.677
572.70	1.090
672.70	1.540
760.95	2.090
CURVE 10	
306	0.052
345	0.206
379	0.348
421	0.475
459	0.660
514	0.929
572	1.153
639	1.475
CURVE 11‡	
315.8	0.080*
345.5	0.184
374.5	0.289*
402.8	0.393
430.4	0.497
457.2	0.600
483.2	0.704
508.6	0.808
533.5	0.911
557.6	1.014
586.6	1.143
620.2	1.298
652.6	1.453
CURVE 12*	
298	0.000
473	0.005
673	0.014

T	$\Delta L/L_0$
CURVE 13*	
298	0.000
473	0.004
673	0.010
873	0.017
CURVE 14*,†	
40	0.000
60	0.004
80	0.013
100	0.029
140	0.080
180	0.168
CURVE 15‡	
293	0.000*
300	0.023*
400	0.377
500	0.781
600	1.233
700	1.730
759	2.042
CURVE 16‡	
71	-0.477
81	-0.469*
96	-0.454
111	-0.436
121	-0.421*
146	-0.381
170	-0.335
196	-0.276
222	-0.210
248	-0.138
272	-0.067*
293	0.000*
297	0.013*
321	0.094
371	0.274*
474	0.681*
522	0.886
551	1.013
575	1.120*

T	$\Delta L/L_0$
CURVE 17	
40	-0.52
60	-0.52
80	-0.51
100	-0.49
140	-0.44
180	-0.35
298	0.004
CURVE 18	
293	0.00*
593	1.24
CURVE 19‡	
133	-0.406
140	-0.394*
146	-0.383*
185	-0.304*
191	-0.290
277	-0.051
277	-0.051*
293	0.000*
313	0.067
316	0.078*
322	0.099*
337	0.152
346	0.185*
414	0.443
448	0.577
500	0.786*
549	0.989
657	1.470
756	1.942
CURVE 20‡	
273	-0.071*
323	0.106
373	0.289
473	0.676
573	1.089
673	1.532*
773	2.005
873	2.509
923	2.774

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 286. THERMAL LINEAR EXPANSION OF LITHIUM FLUORIDE LiF (continued)

T	$\Delta L/L_0$
CURVE 20 (cont.)‡	
973	3.049
1023	3.338
1073	3.647
1123	3.980
CURVE 21	
293	0.000*
303	0.029
323	0.101*
373	0.294*
423	0.482
473	0.672*
500	0.801
CURVE 22*	
293	0.000
313	0.200
CURVE 23*	
293	0.000
313	0.204

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 286. COEFFICIENT OF THERMAL LINEAR EXPANSION OF LITHIUM FLUORIDE LiF

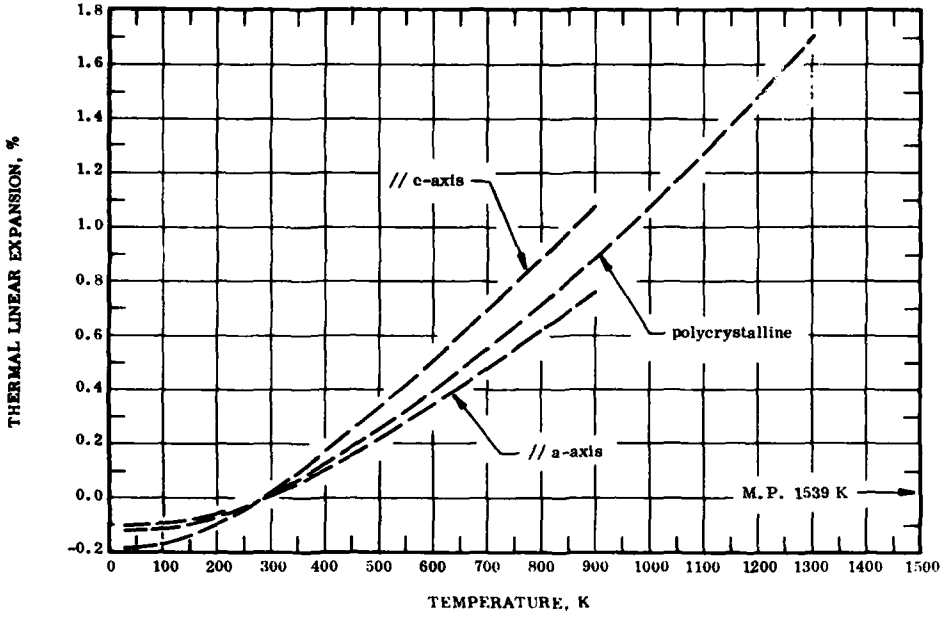
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
223	33
233	34
253	36
273	37
293	38
313	39*
333	41*
353	43*
373	44*
393	45*
413	46*
433	47*
453	49*
473	51*
CURVE 3‡	
223	30
233	32
253	33
273	34
293	36
313	36*
333	37*
353	38*
373	40*
393	41*
413	44*
433	47*
453	49*
473	53*
CURVE 5‡	
4	0.015
5	0.015*
6	0.015*
7	0.015*
8	0.015*
10	0.015*
12	0.015*
14	0.023*
16	0.034
18	0.046*
20	0.063*
22	0.084*
CURVE 5 (cont.)‡	
24	0.110*
26	0.150*
28	0.190*
30	0.240
57.5	2.30
65	3.60
75	5.20
85	7.20
CURVE 6‡	
26	0.4
32	0.4*
36	1.0
39	0.9*
43	0.9
47	1.1
50	0.8
51	0.6*
59	1.5
60	2.9*
62	3.6*
68	4.2
69	4.8*
76	5.3*
79	6.1
84	6.5*
91	7.0*
95	8.7
99	9.2*
106	10.7
113	11.6*
117	13.9
123	13.9
127	14.4*
129	15.3*
131	16.8
133	16.1
136	17.4
140	18.3
143	17.1
144	17.7
148	20.3
151	19.1
154	20.6
157	20.2*
CURVE 6 (cont.)‡	
161	21.0*
167	21.7
169	22.4*
172	23.4
173	22.4*
178	23.1
185	24.4
198	25.8
201	25.8*
206	26.4
210	28.1*
221	28.8
222	28.6*
233	29.3
236	29.9*
252	31.7
256	32.1*
265	32.3
281	33.2
CURVE 11*,‡	
315.8	34.96
345.5	35.55
374.5	36.41
402.8	37.14
430.4	38.15
457.2	39.27
483.2	40.42
508.6	41.07
533.5	42.04
557.6	43.76
586.6	44.99
620.2	47.19
652.6	48.35
CURVE 15*,‡	
293	32.2
300	32.9
400	37.9
500	42.9
600	47.6
700	51.7
759	54.2
CURVE 16‡	
71	7.1
81	9.0
96	11.3
111	13.4
121	14.7
146	17.7*
170	20.8
196	24.2
222	26.6
248	28.8
272	30.9
293	32.5
297	33.0
321	34.5*
371	37.3*
474	41.9*
522	43.4*
551	44.3*
575	44.3*
CURVE 19‡	
133	16.3*
140	17.5*
146	17.7*
185	22.7
191	25.2
277	30.3
277	31.1
293	33.1
313	34.1*
316	35.6*
322	35.0*
337	35.9*
346	36.4*
414	39.5*
448	39.5*
500	40.8*
549	42.2*
657	46.8*
756	48.6*
CURVE 20*,‡	
273	34.7
323	36.0
CURVE 20 (cont.)*,‡	
373	37.3
473	40.0
573	42.7
673	45.8
773	48.8
873	52.0
923	54.0
973	56.2
1023	59.4
1073	63.9
1123	69.6

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 287R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF MAGNESIUM FLUORIDE MgF_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
25	-0.104	-0.191	-0.133	0.1
50	-0.104	-0.191	-0.133	0.3
75	-0.103	-0.188	-0.131	0.8
100	-0.102	-0.181	-0.128	1.8
150	-0.090	-0.153	-0.111	4.8
200	-0.069	-0.110	-0.083	7.2
250	-0.036	-0.056	-0.043	7.5
293	0.000	0.000	0.000	10.3
300	0.005	0.015	0.008	10.4
400	0.104	0.168	0.125	12.1
500	0.213	0.333	0.253	13.4
600	0.334	0.507	0.392	14.5
700	0.468	0.690	0.542	15.8
800	0.618	0.879	0.705	17.1
900	0.785	1.072	0.881	18.5
1000			1.066	19.8†
1100			1.265	21.1†
1200			1.476	22.4†
1300			1.700	23.6†

† Extrapolated values.

REMARKS

The provisional values for the polycrystalline sample are calculated from the selected axial thermal expansion. This result is recommended in preference to the reported data for polycrystalline sample (curve 1) on the suspicion that this sample exhibit partial preferential orientation. The thermal expansion values reported for hot-pressed samples commonly known as Irtran-1 (curves 2, 8 and 11) agree with the calculated provisional values for the polycrystalline samples. These values are considered accurate to within ± 7% at temperatures below 900 K and ± 15% above 900 K. The tabulated values are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -9.907 \times 10^{-2} - 1.871 \times 10^{-4}\ T + 1.465 \times 10^{-6}\ T^2 + 1.156 \times 10^{-9}\ T^3$ (25-293 K)

$\Delta L/L_0 = -0.243 + 7.439 \times 10^{-4}\ T + 2.042 \times 10^{-7}\ T^2 + 2.653 \times 10^{-10}\ T^3$ (293-900 K)

// c-axis: $\Delta L/L_0 = -0.182 - 3.850 \times 10^{-4}\ T + 4.315 \times 10^{-6}\ T^2 - 2.953 \times 10^{-9}\ T^3$ (25-293 K)

$\Delta L/L_0 = -0.394 + 1.171 \times 10^{-3}\ T + 6.383 \times 10^{-7}\ T^2 - 1.433 \times 10^{-10}\ T^3$ (293-900 K)

polycrystalline: $\Delta L/L_0 = -0.127 - 2.329 \times 10^{-4}\ T + 2.267 \times 10^{-6}\ T^2 + 7.551 \times 10^{-11}\ T^3$ (25-293 K)

$\Delta L/L_0 = -0.275 + 7.864 \times 10^{-4}\ T + 5.235 \times 10^{-7}\ T^2 + 3.107 \times 10^{-11}\ T^3$ (293-1300 K)

The tabulated values for the coefficient of thermal expansion at temperatures below 293 K are based on the selected experimental data (curve 8) and those above 293 K are calculated by differentiating the above equation for polycrystalline sample.

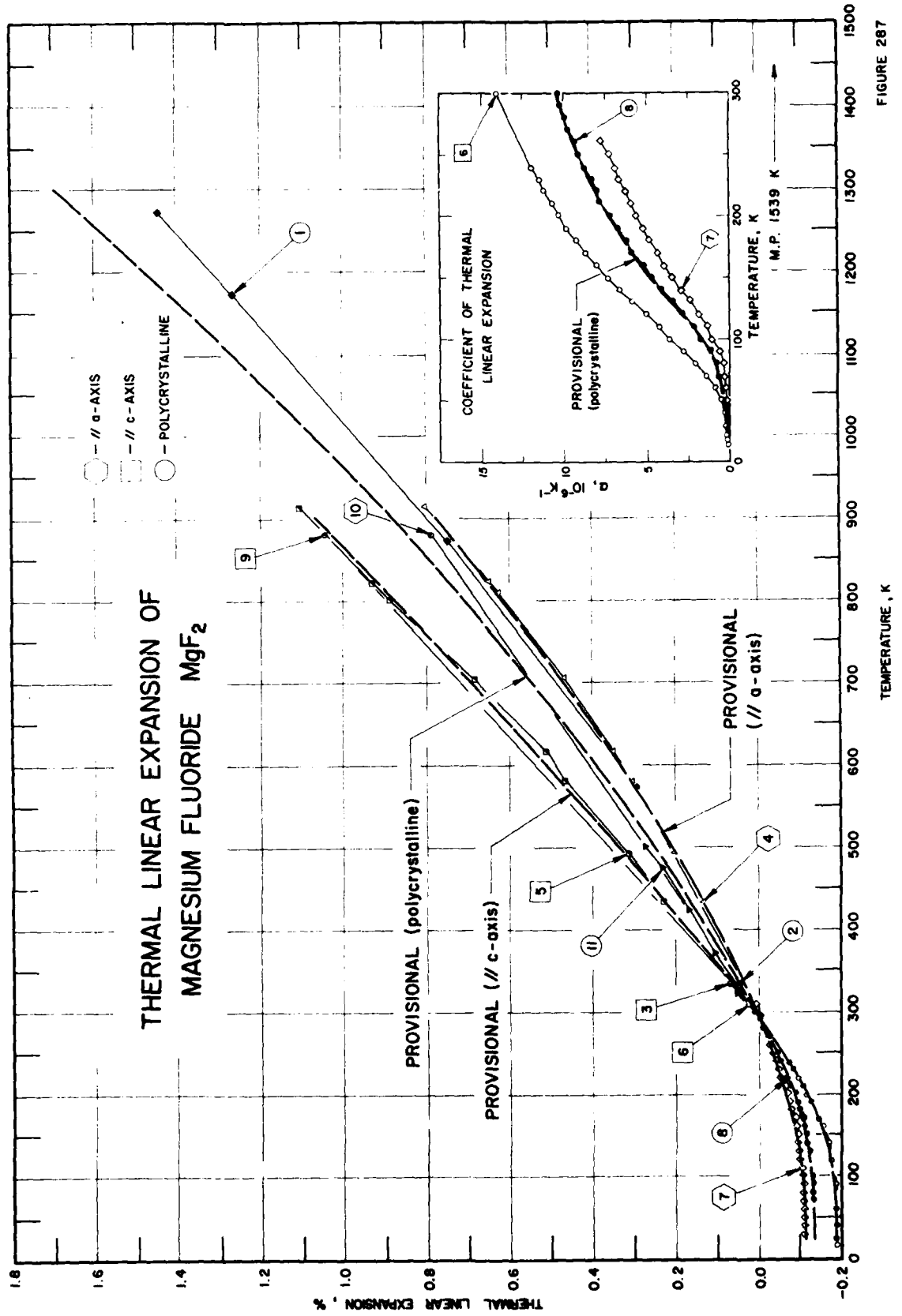

THERMAL LINEAR EXPANSION OF
MAGNESIUM FLUORIDE MgF_2
// a-AXIS
// c-AXIS
POLYCRYSTALLINE
PROVISIONAL (polycrystalline)
PROVISIONAL (// c-axis)
PROVISIONAL (// a-axis)
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
M.P. 1539 K
COEFFICIENT OF THERMAL LINEAR EXPANSION
PROVISIONAL (polycrystalline)
α, 10⁻⁶ K⁻¹
TEMPERATURE, K

FIGURE 287

SPECIFICATION TABLE 287. THERMAL LINEAR EXPANSION OF MAGNESIUM FLUORIDE MgF_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1	Whittemore, O.J., Jr. and Ault, N.N.	1956	T	298-1273		Specimen with a cross section 1.3 x 1.3 and 17.8 cm long; the ends sawed at a rake and to a point; fine grain.
2	148	Ballard, S.S. and Browder, J.S.	1966	I	273-333	Irtran 1	Infrared-transmitting optical material; microcrystalline; hot-pressed compact developed by the Eastman Kodak Co. of New York; low emissivity, high transmittance uncoated; at 298 K transmittance 0.5 to 9 μ, density 3.18 g cm^{-3}.
3	148	Ballard, S.S. and Browder, J.S.	1966	I	273-333		Single crystal; produced by Harshaw Co.; density 3.18 g cm^{-3} at 3.3 μ refractive index 1.376; long-wavelength transmission limit 7.5 μ; expansion measured parallel to c-axis.
4	326	Rao, K.V.K., Naidu, S.V.N., and Setty, P.L.N.	1962	X	303-913		Aluminum used as internal standard; expansion measured along a-axis using Cu Kα radiation from Raymax 60 diffraction unit; lattice constant reported at 303 K as 4.6218 Å; 4.6214 Å at 293 K determined by graphical extrapolation; coefficient of thermal expansion also reported.
5	326	Rao, K.V.K., et al.	1962	X	303-913		The above specimen except expansion measured along c-axis; lattice constant reported at 303 K as 3.0534 Å; 3.0520 Å at 293 K determined by graphical extrapolation; coefficient of thermal expansion also reported.
6	327	Browder, J.S.	1967	E	16-310		Clear single crystal grown using Stockbarger technique; right cylinder specimen 6.35 mm in diameter, 12.7 mm long; opposite ends of sample polished parallel to within 0.0025 mm; density 3.18 g cm^{-3}; expansion measured parallel to c-axis.
7	327	Browder, J.S.	1967	E	30-310		The above specimen; expansion measured perpendicular to c-axis.
8	327	Browder, J.S.	1967	E	70-310	Irtran 1	Polycrystalline specimen; artificially produced infrared-transmitting optical sample; right cylinder 6.35 mm in diameter, 12.7 mm long; opposite ends polished parallel to within 0.0025 mm; density 3.18 g cm^{-3}.
9	782	Rao, K.V.K.	1967	X	298, 883		Expansion measured along c-axis.
10	782	Rao, K.V.K.	1967	X	298, 883		The above specimen; expansion measured along a-axis.
11	791	Murat, M., Chatelut, F., and Bardot, C.	1969	L	293-500		Spherical grain size 0.3 - 1μm rectangular bar; pulverized powder pressed at 22,335 psi; subjected to thermal cycles of 573 K/hr; zero-point correction is 0.016% at 293 K.

DATA TABLE 287. THERMAL LINEAR EXPANSION OF MAGNESIUM FLUORIDE MgF_2

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %)

CURVE 1

T	$\Delta L/L_0$
298	0.005
573	0.299
873	0.754
1173	1.276
1273	1.450

CURVE 2

T	$\Delta L/L_0$
273	-0.021*
298	0.005*
333	0.046

CURVE 3

T	$\Delta L/L_0$
273	-0.031*
298	0.007*
333	0.066

CURVE 4

T	$\Delta L/L_0$
303	0.008
431	0.131
491	0.203
580	0.305
615	0.348
706	0.467
810	0.629
823	0.651
913	0.807

CURVE 5

T	$\Delta L/L_0$
303	0.045*
431	0.229
491	0.317
580	0.468
615	0.514
706	0.681
810	0.887
823	0.937
913	1.107

CURVE 6‡

T	$\Delta L/L_0$
16	-0.195
18	-0.195*
20	-0.195*
22	-0.195
24	-0.195*
26	-0.195*
28	-0.195*
30	-0.195*
40	-0.195
50	-0.194*
60	-0.194
70	-0.192*
80	-0.191*
90	-0.188
100	-0.185*
110	-0.181*
120	-0.176
130	-0.170*
140	-0.164
150	-0.157*
160	-0.149*
170	-0.141
180	-0.132*
190	-0.123
200	-0.113
210	-0.102
220	-0.091
230	-0.080
240	-0.069
300	0.009*
310	0.023

CURVE 7‡

T	$\Delta L/L_0$
30	-0.103
40	-0.103
50	-0.103
60	-0.103
70	-0.102
80	-0.102
90	-0.102
100	-0.101
110	-0.100
120	-0.098

CURVE 7 (cont.)‡

T	$\Delta L/L_0$
130	-0.096
140	-0.093
150	-0.090
160	-0.086
170	-0.082
180	-0.077
190	-0.072
200	-0.067
210	-0.061
220	-0.055
230	-0.049
240	-0.042
250	-0.035
260	-0.027
310	0.014

CURVE 8‡

T	$\Delta L/L_0$
70	-0.131
80	-0.130
90	-0.129
100	-0.127
110	-0.125*
120	-0.123*
130	-0.120
140	-0.116
150	-0.112
160	-0.107
170	-0.101
180	-0.095
190	-0.08
200	-0.082
210	-0.075
220	-0.067
230	-0.059*
240	-0.050
250	-0.041
260	-0.032*
270	-0.023
280	-0.013
290	-0.003
300	0.007*
310	0.018*

CURVE 9

T	$\Delta L/L_0$
298	0.007
883	1.045

CURVE 10

T	$\Delta L/L_0$
298	0.005
883	0.792

CURVE 11

T	$\Delta L/L_0$
293	0.000*
303	0.016*
323	0.050
373	0.108
423	0.169
473	0.236
500	0.276

*Not shown in figure.

‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 287. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MAGNESIUM FLUORIDE MgF_2

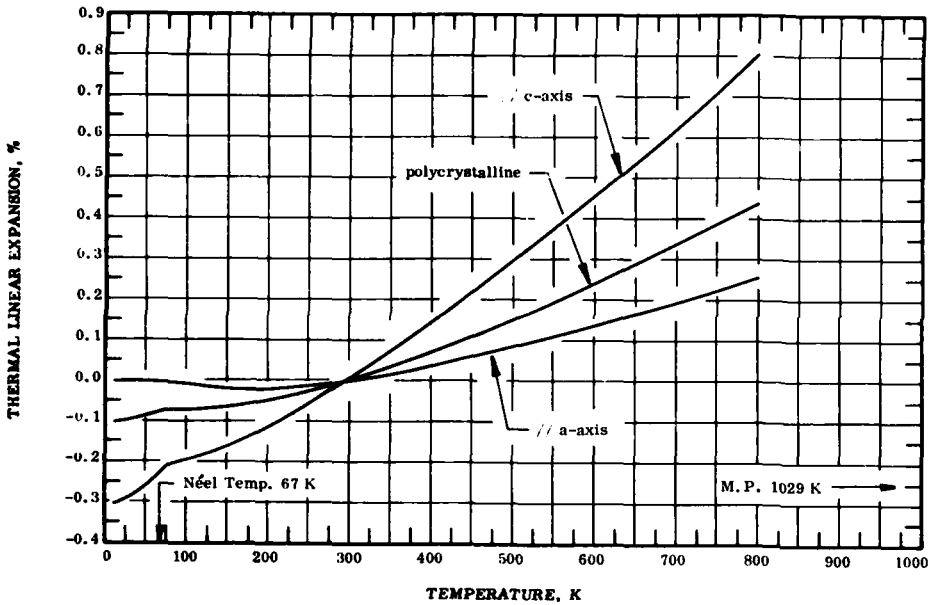
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 4*	
323	9.6
363	10.0
403	10.2
443	10.5
483	11.1
523	11.8
563	12.1
603	12.6
643	13.2
683	13.7
723	14.7
763	15.3
803	15.9
843	16.6
883	17.5
CURVE 5*	
323	13.7
363	14.2
403	14.5
443	15.1
483	15.5
523	15.9
563	16.5
603	17.0
643	17.5
683	18.0
723	19.0
763	19.6
803	20.1
843	21.1
883	22.0
CURVE 6‡	
16	0.04
18	0.06
20	0.08
22	0.11
24	0.14
26	0.17
28	0.21
30	0.25
40	0.38
50	0.53
60	0.91
CURVE 6 (cont.)‡	
70	1.49
80	2.10
90	2.72
100	3.55
110	4.27
120	5.10
130	5.92
140	6.63
150	7.38
160	8.00
170	8.61
180	9.15
190	9.66
200	10.15
210	10.60
220	11.03
230	11.45
240	11.86
300	13.90
310	14.21*
CURVE 7‡	
30	0.04*
40	0.09
50	0.12
60	0.20
70	0.26
80	0.40
90	0.62
100	1.03
110	1.45
120	1.97
130	2.44
140	2.90
150	3.42
160	3.88
170	4.36
180	4.78
190	5.18
200	5.57
210	5.94
220	6.28
230	6.63
240	6.97
250	7.31
260	7.65
310	8.91*
CURVE 8‡	
70	0.60
80	0.78
90	1.20
100	1.75
110	2.25
120	2.87
130	3.45
140	4.02
150	4.63
160	5.22
170	5.70
180	6.18
190	6.65
200	7.13
210	7.7
220	7.9
230	8.3
240	8.6
250	9.0
260	9.3
270	9.6
280	9.9
290	10.2
300	10.4
310	10.7*

*Not shown in figure.

‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 288R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF MANGANESE FLUORIDE MnF_2



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
10	-0.001	-0.301	-0.101	
25	-0.001	-0.294	-0.099	
50	-0.001	-0.262	-0.088	5.5
60	-0.001	-0.238	-0.080	8.4
67†	-0.001	-0.221	-0.074	18.5
70	-0.001	-0.212	-0.071	3.5
80	-0.002	-0.202	-0.069	-0.1
100	-0.009	-0.192	-0.070	0.2
150	-0.019	-0.155	-0.064	2.4
200	-0.019	-0.106	-0.048	4.0
250	-0.011	-0.051	-0.024	5.3
293	0.000	0.000	0.000	6.1
300	0.002	0.009	0.004	6.3
350	0.019	0.074	0.037	6.9
400	0.038	0.143	0.073	7.5
450	0.059	0.216	0.111	8.0
500	0.083	0.293	0.153	8.5
550	0.108	0.372	0.196	8.9
600	0.135	0.455	0.242	9.3
650	0.164	0.539	0.289	9.7
700	0.195	0.625	0.338	10.0
750	0.226	0.713	0.388	10.2
800	0.259	0.803	0.440	10.4

† Néel temperature.

REMARKS

The recommended values for the axial thermal expansion are based on curve 1 and 2 (50-280 K) and curves 3 and 4 (303-770 K) which are consistent with one another. The values for the polycrystalline sample are calculated from these values. The recommended values are considered accurate to within ± 5% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = 4.548 \times 10^{-2} - 7.958 \times 10^{-4} T + 2.731 \times 10^{-6} T^2 - 1.826 \times 10^{-9} T^3$ (80-293 K)

$\Delta L/L_0 = -3.833 \times 10^{-2} - 6.089 \times 10^{-5} T + 7.143 \times 10^{-7} T^2 - 2.169 \times 10^{-10} T^3$ (293-800 K)

// c-axis: $\Delta L/L_0 = -0.216 - 1.765 \times 10^{-4} T + 4.738 \times 10^{-6} T^2 - 5.561 \times 10^{-9} T^3$ (80-293 K)

$\Delta L/L_0 = -0.275 + 5.902 \times 10^{-4} T + 1.332 \times 10^{-6} T^2 - 4.827 \times 10^{-10} T^3$ (293-800 K)

polycrystalline: $\Delta L/L_0 = -3.587 \times 10^{-2} - 6.877 \times 10^{-4} T + 3.892 \times 10^{-6} T^2 - 3.834 \times 10^{-9} T^3$ (80-293 K)

$\Delta L/L_0 = -0.116 + 1.502 \times 10^{-4} T + 9.331 \times 10^{-7} T^2 - 3.141 \times 10^{-10} T^3$ (293-800 K)

The tabulated values for the coefficient of thermal expansion below 293 K are calculated from the axial data (curves 1 and 2) and above 293 K, the values are calculated by differentiating the above equation for the polycrystalline sample. These values are considered accurate to about ± 7% above 293 K and ± 10% below 293 K.

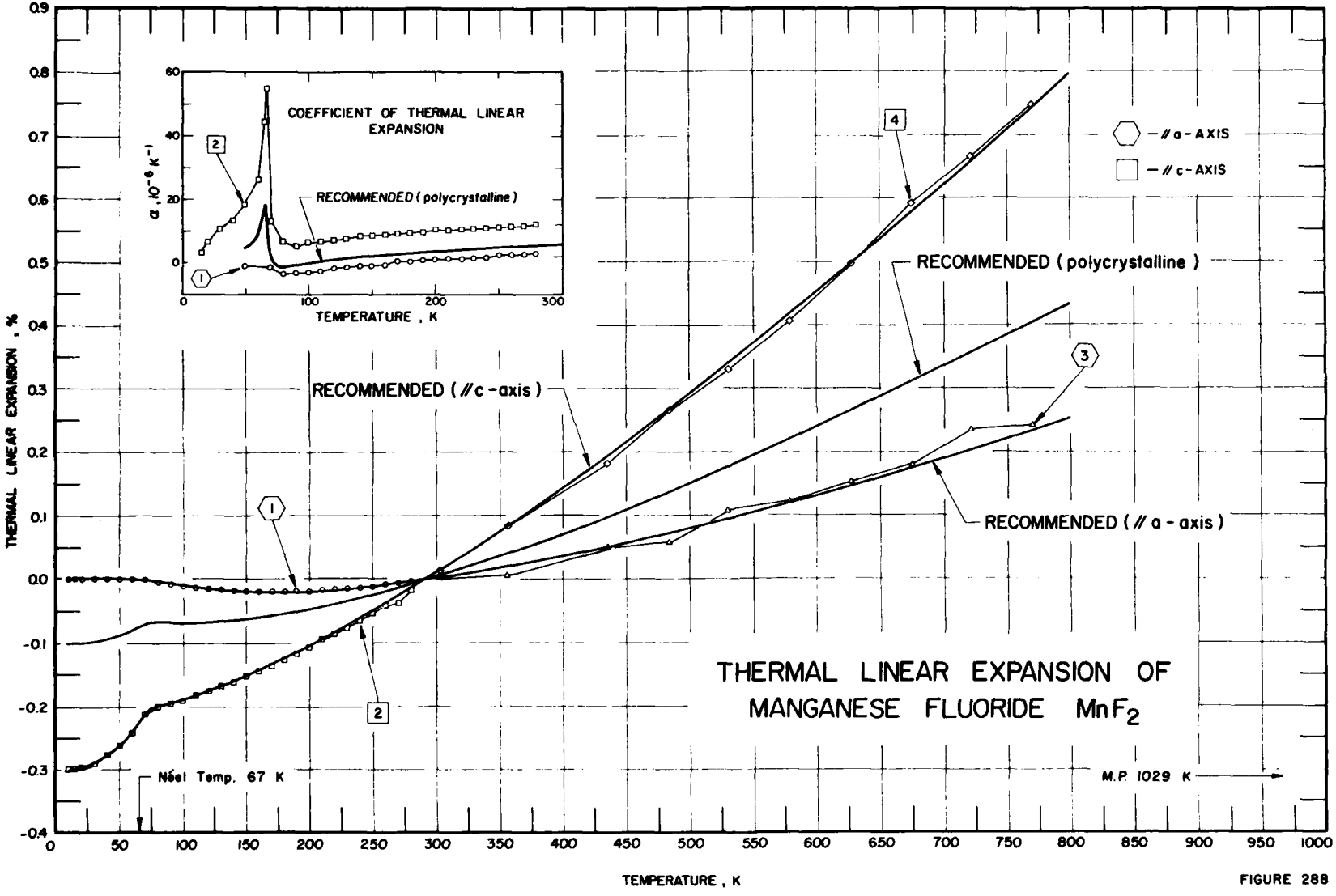

THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
RECOMMENDED (polycrystalline)
TEMPERATURE , K
// a - AXIS
// c - AXIS
RECOMMENDED (polycrystalline)
RECOMMENDED (// c - axis)
RECOMMENDED (// a - axis)
THERMAL LINEAR EXPANSION OF
MANGANESE FLUORIDE MnF2
Néel Temp. 67 K
M.P. 1029 K

FIGURE 288

SPECIFICATION TABLE 288. THERMAL LINEAR EXPANSION OF MANGANESE FLUORIDE MnF_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	792	Gibbons, D. F.	1959	I	10-280		Single crystal grown by J. M. Nielson of Bell Telephone Laboratories, Inc., specimen cut parallel to a-axis; expansion measured along a-axis; negative slope at Néel temperature due to antiferromagnetic ordering; coefficient of thermal linear expansion also reported.
2	792	Gibbons, D. F.	1959	I	10-280		Similar to the above specimen; specimen cut parallel to c-axis; expansion measured along c-axis; Néel temperature accounted for change of slope at 67 K; coefficient of thermal linear expansion also reported.
3	781	Rao, K. V. K. and Naidu, S. V. N.	1963	X	303-770		Sample from pure crystal grown from melt, supplied by General Electric Co., N. Y.; expansion measured along a-axis.
4	781	Rao, K. V. K. and Naidu, S. V. N.	1963	X	303-770		The above specimen; expansion measured along c-axis; lattice parameter reported at 303 K as 3.3107 Å; 3.3103 Å at 293 K determined by graphical extrapolation.
5*	782, 783	Rao, K. V. K.	1969	X	298, 723		Expansion measured along c-axis.
6*	782, 783	Rao, K. V. K.	1969	X	298, 723		The above specimen; expansion measured along a-axis.

* Not shown in figure.

DATA TABLE 288. THERMAL LINEAR EXPANSION OF MANGANESE FLUORIDE MnF_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 2		CURVE 2 (cont.)		CURVE 3		CURVE 4 (cont.)	
10	-0.001	160	-0.021	10	-0.032	160	-0.144	303	0.000	483	0.265
15	-0.001	170	-0.021	15	-0.301	170	-0.135	357	0.004	531	0.329
20	-0.001	180	-0.021	20	-0.299	180	-0.126	434	0.050	579	0.407
30	-0.001	190	-0.020	30	-0.290	190	-0.116	483	0.058	627	0.498
40	-0.001	200	-0.020	40	-0.278	200	-0.106	531	0.109	674	0.592
50	-0.001	210	-0.018	50	-0.262	210	-0.096	579	0.121	722	0.667
60	-0.002	220	-0.017	60	-0.240	220	-0.085	627	0.152	770	0.749
70	-0.003	230	-0.016	70	-0.211	230	-0.075	674	0.179		
80	-0.005	240	-0.014	80	-0.202	240	-0.064	722	0.236	CURVE 5*	
90	-0.009	250	-0.012	90	-0.196	250	-0.052	770	0.242		
100	-0.012	260	-0.009	100	-0.190	260	-0.041			298	0.006
110	-0.014	270	-0.007	110	-0.183	270	-0.027	CURVE 4		723	0.812
120	-0.017	280	-0.004	120	-0.176	280	-0.017				
130	-0.018			130	-0.168			303	0.012	CURVE 6*	
140	-0.020			140	-0.160			357	0.084		
150	-0.020			150	-0.152			434	0.181	298	0.001
										723	0.331

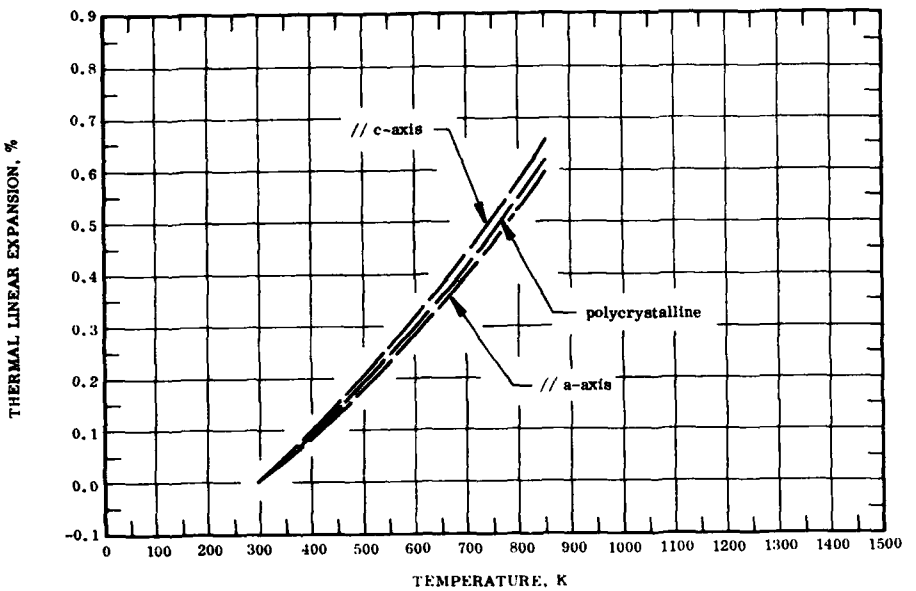
DATA TABLE 288. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MANGANESE FLUORIDE MnF_2

[Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\,K^{-1}$]

T	α	T	α	T	α	T	α
CURVE 1		CURVE 1 (cont.)		CURVE 2 (cont.)		CURVE 2 (cont.)	
50	-0.99	210	1.21	60	26.29	200	10.11
60	-0.55*	220	1.48	65	44.43	210	10.38
70	-1.46	230	1.71	67	55.83	220	10.67
80	-3.46	240	1.94	70	13.34	230	10.93
90	-3.20	250	2.22	80	6.59	240	11.15
100	-2.84	260	2.50	90	5.34	250	11.47
110	-2.40	270	2.78	100	6.36	260	11.73
120	-1.93	280	3.02	110	6.97	270	12.03
130	-1.56			120	7.45	280	12.23
140	-1.17	CURVE 2		130	7.86		
150	-0.76			140	8.23		
160	-0.40	15	3.25	150	8.57		
170	0.06	20	6.40	160	8.92		
180	0.39	30	10.33	170	9.22		
190	0.70	40	13.85	180	9.54		
200	0.97	50	18.35	190	9.83		

* Not shown in figure.

FIGURE AND TABLE NO. 289R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF NICKEL FLUORIDE NiF_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	8.0
300	0.005	0.006	0.006	8.0
350	0.044	0.053	0.047	8.5
400	0.085	0.101	0.091	9.0
450	0.129	0.152	0.137	9.5
500	0.176	0.205	0.186	10.1
550	0.226	0.260	0.238	10.7
600	0.280	0.318	0.293	11.3
650	0.337	0.379	0.351	12.0
700	0.398	0.443	0.413	12.7
750	0.463	0.509	0.479	13.5
800	0.532	0.579	0.548	14.2
850	0.606	0.651	0.621	15.1

REMARKS

The provisional values for the axial thermal linear expansion are based on the data for high purity powder specimen. The provisional values for the polycrystalline sample are derived from these values. These values are considered accurate to within ±7% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.182 + 5.250 \times 10^{-4}\ T + 2.549 \times 10^{-7}\ T^2 + 2.565 \times 10^{-10}\ T^3$

// c-axis: $\Delta L/L_0 = -0.234 + 7.093 \times 10^{-4}\ T + 2.596 \times 10^{-7}\ T^2 + 1.544 \times 10^{-10}\ T^3$

polycrystalline: $\Delta L/L_0 = -0.201 + 5.967 \times 10^{-4}\ T + 2.406 \times 10^{-7}\ T^2 + 2.304 \times 10^{-10}\ T^3$

The tabulated values for the coefficient of thermal expansion are calculated from the axial experimental data and are considered accurate to about ±10%.

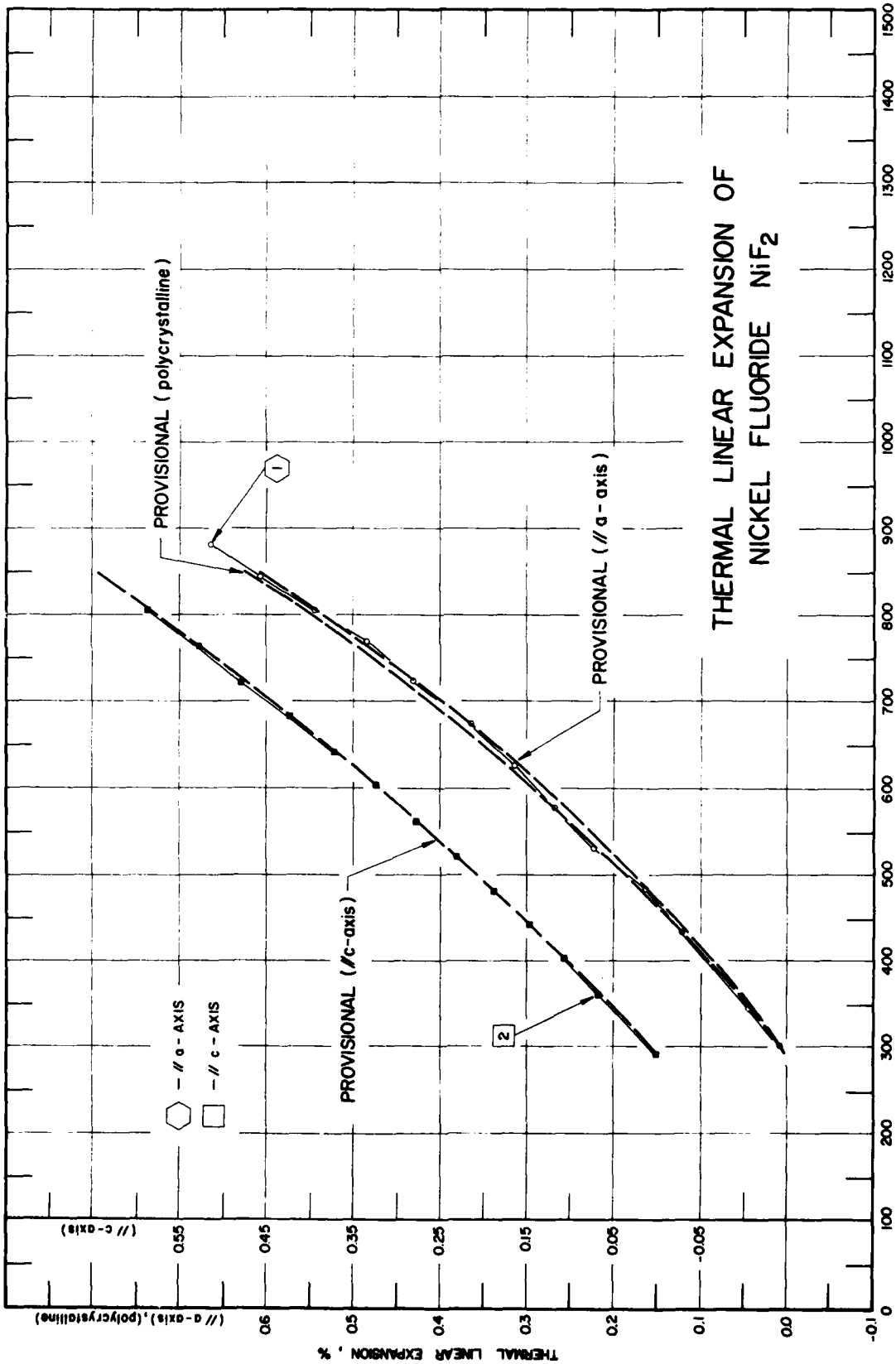

THERMAL LINEAR EXPANSION OF
NICKEL FLUORIDE NiF_2
PROVISIONAL (polycrystalline)
PROVISIONAL (// a - axis)
PROVISIONAL (// c - axis)
1
2
— // a - AXIS
— // c - AXIS
THERMAL LINEAR EXPANSION , %
(// a - axis), (polycrystalline)
(// c - axis)
TEMPERATURE , K

FIGURE 289

SPECIFICATION TABLE 289. THERMAL LINEAR EXPANSION OF NICKEL FLUORIDE NiF_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	793	Rao, K.V.K., Naidu, S.V.N., and Iyengar, L.	1968	X	301-881		Powder specimen supplied from Prof. J. W. Stout of University of Chicago; expansion measured along a-direction; lattice parameter reported at 301 K as 4.6498 Å; 4.6494 Å at 293 K determined by graphical extrapolation; coefficient of thermal linear expansion also reported from 323 K to 848 K.
2	793	Rao, K.V.K., et al.	1968	X	293-848		The above specimen; measured along c-direction.
3*	782	Rao, K.V.K.	1969	X	298, 843		Expansion measured along c-axis.
4*	782	Rao, K.V.K.	1969	X	298. 843		The above specimen except expansion measured along a-axis.
5*	791	Murat, M., Chatelut, F., and Bardot, C.	1971	L	293-504		Rectangular bar; pulverized powder pressed at 22, 335 psi subjected to thermal cycles of 573 K/hr; zero-point correction is 0.006% at 293 K.
6*	783	Rao, K.V.K.	1974	X	298, 863		No details given.

* Not shown in figure.

DATA TABLE 289. THERMAL LINEAR EXPANSION OF NICKEL FLUORIDE NiF_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
301	0.007
343	0.044
434	0.121
483	0.162
531	0.222
579	0.269
627	0.314
674	0.366
722	0.431
770	0.484
807	0.545
844	0.607
881	0.663
CURVE 2	
293	0.000
323	0.027
363	0.065
403	0.104
443	0.145
483	0.187
523	0.230
563	0.275
603	0.322
643	0.371
686	0.422
726	0.474
766	0.528
806	0.585
848	0.643*
CURVE 3*	
298	0.005
843	0.814
CURVE 4*	
298	0.003
843	0.841
CURVE 5*	
293	0.000
303	0.006
323	0.022
335	0.033
355	0.043
373	0.043
401	0.021
423	0.002
440	-0.031
473	-0.082
504	-0.146
CURVE 6*	
298	0.004
863	0.843

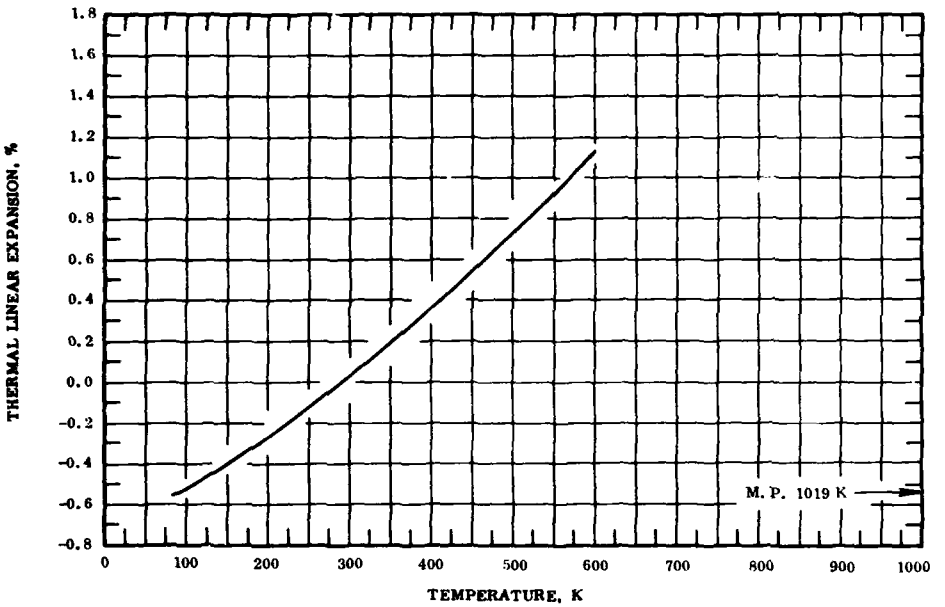
DATA TABLE 289. *COEFFICIENT OF THERMAL LINEAR EXPANSION OF NICKEL FLUORIDE* NiF_2

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1*	
323	7.33
363	7.74
403	8.28
444	8.81
485	9.21
525	9.84
565	10.30
604	10.90
645	11.59
685	12.29
727	12.92
767	13.71
806	14.44
848	15.44
CURVE 2*	
293	9.06
323	9.34
363	9.60
403	9.84
443	10.24
483	10.70
523	11.03
563	11.53
603	11.96
643	12.45
686	12.93
726	13.18
766	13.92
806	14.33
848	14.74
CURVE 3*	
298	9.0
843	14.8
CURVE 4*	
298	7.2
843	15.3
CURVE 6*	
298	9.0
863	14.8

* Not shown in figure.

FIGURE AND TABLE NO. 290R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF POTASSIUM FLUORIDE KF



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
80	-0.515	16.7
100	-0.519	19.2
150	-0.410	24.3
175	-0.345	26.3
200	-0.275	27.8
225	-0.204	29.3
250	-0.131	30.3
275	-0.055	31.1
293	0.000	31.2
300	0.022	31.4
350	0.183	33.1
400	0.353	35.0
450	0.533	37.0
500	0.723	39.1
550	0.925	41.4
600	1.137	43.7

REMARKS

The recommended values are based on the most recent measurements. These values are considered accurate to within ±5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.787 + 2.330 \times 10^{-3}\, T + 9.810 \times 10^{-7}\, T^2 + 8.024 \times 10^{-10}\, T^3 \quad (150\text{-}600\ K)$$

The tabulated values for the coefficient of thermal expansion are based on the above measurement and considered accurate to about ±10%.

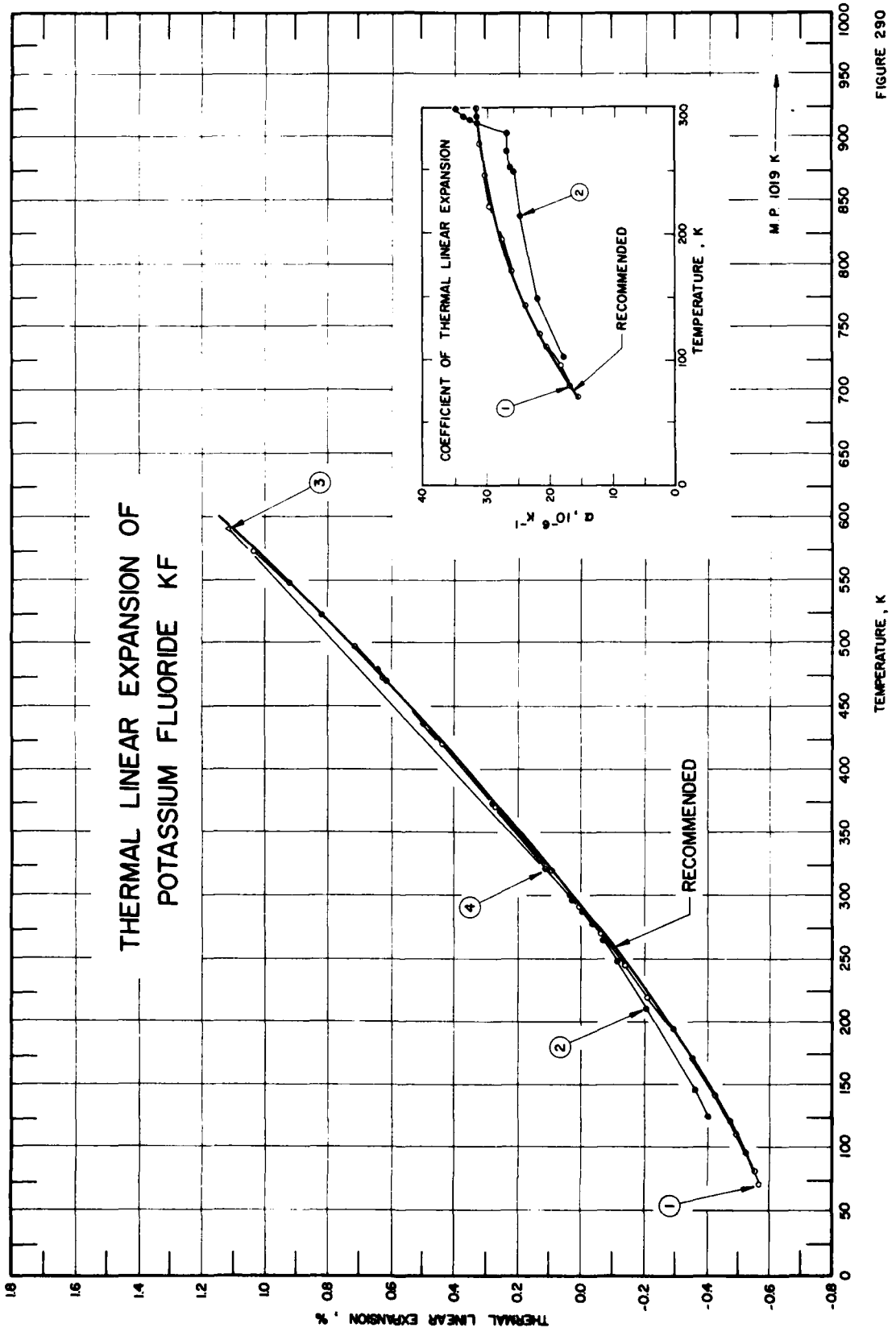

THERMAL LINEAR EXPANSION OF
POTASSIUM FLUORIDE KF
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED
M.P. 1019 K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K
RECOMMENDED
1
2
3
4

FIGURE 290

SPECIFICATION TABLE 290. THERMAL LINEAR EXPANSION OF POTASSIUM FLUORIDE KF

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	771	Rapp, J. E. and Merchant, H. D.	1972	L	71-575		Crystal orientation was <1, 0, 0>; dimensions were 5 x 5 x 50 mm; smoothed data.
2	663	Von Trost, K. E.	1963		127-481		No details given.
3	664	Whittemore, D. O.	1962	L	293, 593		Cylindrical specimen; 1.27 cm diameter x 2.54 cm long; specimen made by pressing reagent grade chemicals into a steel mold at 703 kg-cm^{-2}; original length by micrometer to 2.5 μm; measurement taken with two cylinders placed end to end.
4	791	Chatelut, F., Murat, M., and Bardot, C.	1971	L	293-500		Rectangular bars, pulverized powder pressed at 9427 psi and subjected to thermal cycles of 573 K/hr; zero-point correction is 0.029% at 293 K.

DATA TABLE 290. THERMAL LINEAR EXPANSION OF POTASSIUM FLUORIDE KF

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 2 (cont.)‡		CURVE 4 (cont.)	
71	-0.569	475	0.621	293	0.000*	303	0.029
81	-0.553	525	0.816	299	0.021	323	0.101
96	-0.527	550	0.920	304	0.038*	373	0.271*
111	-0.497	575	1.030	321	0.094*	423	0.434*
121	-0.476			375	0.275	473	0.606
143	-0.427	CURVE 2‡		438	0.491	500	0.772
171	-0.357			481	0.640		
195	-0.292	127	-0.405				
221	-0.219	148	-0.363	CURVE 3			
246	-0.145	214	-0.210				
271	-0.069	250	-0.120	293	0.00*		
293	0.000	253	-0.112*	593	1.15		
297	0.013*	266	-0.077				
321	0.089	280	-0.040	CURVE 4			
374	0.264	288	-0.016*				
423	0.433	290	-0.010	293	0.000*		

DATA TABLE 290. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POTASSIUM FLUORIDE KF

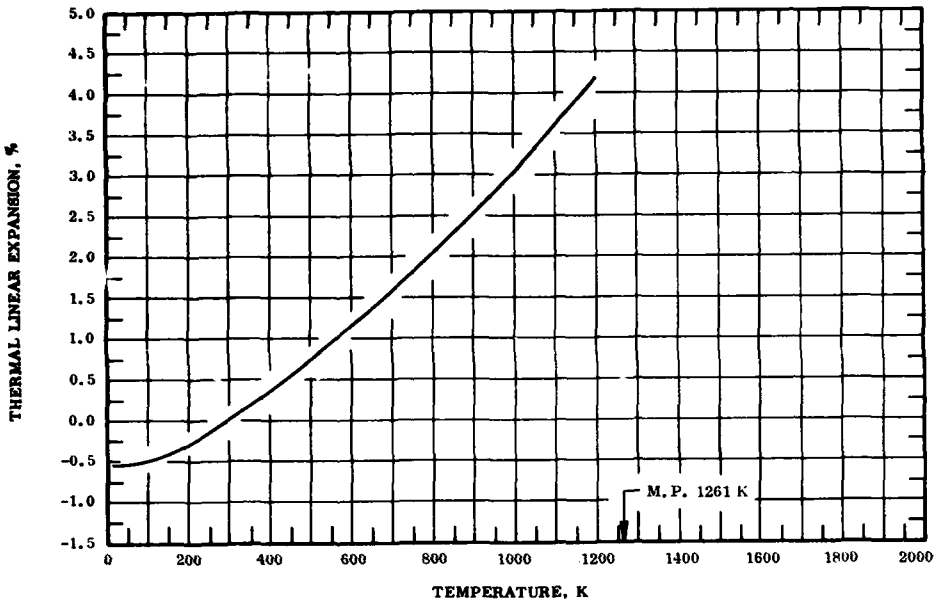
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 2 (cont.)‡	
71	15.3	525	40.6*	304	33.8*
81	16.9	550	42.7*	321	32.9*
96	18.8	575	45.4*	375	33.9*
111	20.3			438	34.7*
121	21.4	CURVE 2‡		481	34.7*
143	23.9				
171	26.0	127	17.9		
195	27.5	148	21.9		
221	29.2	214	24.5		
246	30.0	250	25.8		
271	31.0	253	26.4		
293	31.3	266	26.9		
297	31.4	280	26.9		
321	32.3*	288	31.5		
374	33.7*	290	32.6		
423	35.3*	293	33.6		
475	37.2*	299	34.8		

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 291R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SODIUM FLUORIDE NaF



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
10	-0.546	0.4
15	-0.548	0.4
20	-0.550	0.5
25	-0.551	0.6
50	-0.547	3.0
75	-0.530	9.2
100	-0.500	14.4
150	-0.409	22.5
200	-0.285	27.4
250	-0.137	30.9
293	0.000	33.0
300	0.022	33.5
350	0.199	36.0
400	0.381	37.0
450	0.568	38.0
500	0.759	38.5
600	1.159	41.4
700	1.584	44.3
800	2.036	46.4
900	2.520	49.5
1000	3.037	53.4
1100	3.591	57.5
1200	4.185	62.3

REMARKS

The recommended values are based on the data for high-purity samples. These values are considered accurate to within ±3% at temperatures below 750 K and to within ±5% above that temperature and are represented approximately by the following equations:

$$\Delta L/L_0 = -0.539 - 7.813 \times 10^{-4}\, T + 1.313 \times 10^{-5}\, T^2 - 1.430 \times 10^{-8}\, T^3 \quad (10\text{-}293\ K)$$

$$\Delta L/L_0 = -0.972 + 3.163 \times 10^{-3}\, T + 3.475 \times 10^{-7}\, T^2 + 4.976 \times 10^{-10}\, T^3 \quad (293\text{-}1200\ K)$$

The tabulated values for the coefficient of thermal expansion are primarily calculated from the experimental data and are considered accurate to about ±7%.

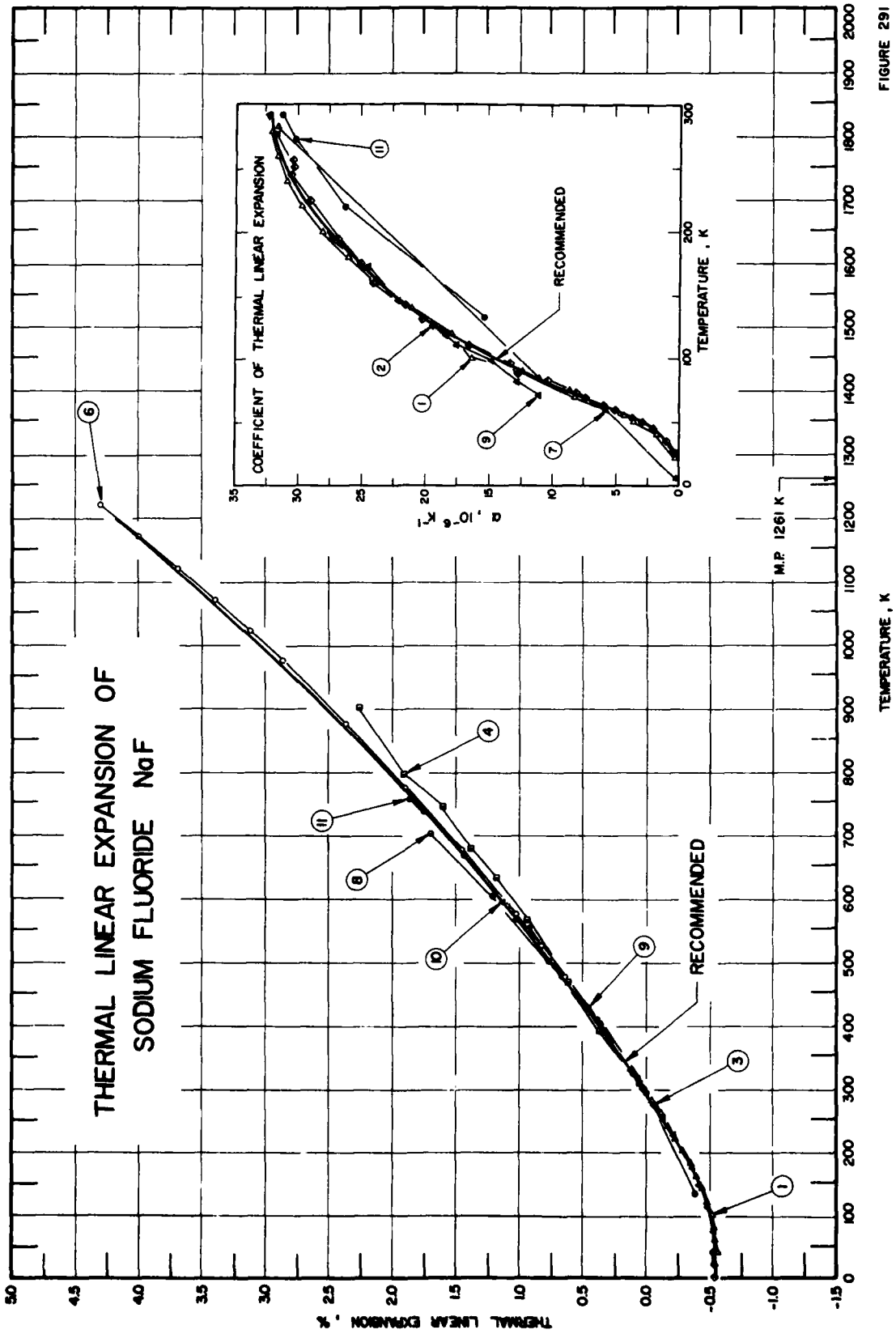

THERMAL LINEAR EXPANSION OF
SODIUM FLUORIDE NaF
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
M.P. 1261 K
RECOMMENDED
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K
RECOMMENDED

FIGURE 291

SPECIFICATION TABLE 291. THERMAL LINEAR EXPANSION OF SODIUM FLUORIDE NaF

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	796	Loje, K. F.	1967	X	40-280		Crystal purchased in form of 2.54 x 2.54 x 1.27 cm; cleavage cube from the Harshaw Chemical Co. of Cleveland, Ohio; a piece cube cleaved off and shaped to 12 mm x 9 mm x 4 mm size, annealed slowly to about 973 K, then slowly cooled to room temperature, process took 2 days; liquid nitrogen used; measurement at 3 x 10^{-6} mm of Hg; five runs in temperature region 100 K to 290 K and three runs between 25 K and 110 K, data calculated and smoothed values from eight runs; reported error < 6%.
2*	797	James, B.W. and Yates, B.	1965	I	20-257		Single crystal hollow cylinder specimen, 2.7 cm O.D., 1.8 cm I.D., and 1 cm long; obtained from Harshaw Chemicals Ltd., Cleveland, Ohio; impurity less than 2 parts in 10,000; reported error 2-15%.
3	798	Laquer, H. L.	1952	L	0-300	No. 1	Dimensions: 1.35 cm long; specimens machined from pressed cake; data average from two specimens; zero-point correction is -0.061% at 293 K.
4	157	Pathak, P.D., Pandya, N.V., and Ghadiali, M.P.	1962	X	306-900		Lattice parameter reported at 306 K as 4.6191 Å; 4.6167 Å at 293 K determined by graphical extrapolation.
5*	799	Deshpande, V.T.	1961	X	302-527		Lattice parameter reported at 302.6 K as 4.6340 Å; 4.6320 Å at 293 K determined by graphical extrapolation; reported error ± 0.01%.
6	628	Pathak, P.D., Trivedi, J.M., and Vasavada, N.G.	1973	X	273-1223		Powder specimen.
7*	623	White, G.K. and Collins, J.G.	1973	E	5-283		Specimen obtained from Harshaw Chemicals of Ohio; cylindrical specimen 20 mm diameter, 50.8 mm long; this curve is here reported utilizing other coefficients of thermal linear expansion from 85 K to 283 K for integration purposes.
8	625	Srivastava, K.K. and Merchant, H.D.	1972	X	293-700		No details given.
9	771	Rapp, J.E. and Merchant, H.D.	1972	L	72-579		Crystal orientation was < 1, 0, 0 >; dimensions were 5 x 5 x 50 mm; smoothed data.
10	664	Whittemore, D.O.	1962	L	293, 593		Two 1.27 cm diameter x 2.54 cm long reagent grade chemical (powder) specimens, which were pressed in a steel mold at 10,000 psi were combined into one cylinder.
11	663	Von Trost, K.F.	1963		134-759		No details given.
12*	791	Murat, M., Chatelut, F., and Bardot, C.	1971	L	293-500		Rectangular bar; pulverized powder pressed at 22,335 psi subject to thermal cycles of 573 K/hr; zero-point correction is 0.029% at 293 K.

* Not shown in figure.

DATA TABLE 291. THERMAL LINEAR EXPANSION OF SODIUM FLUORIDE NaF

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1‡

T	$\Delta L/L_0$
40	-0.554
50	-0.552*
60	-0.547
70	-0.540*
80	-0.531
90	-0.519*
100	-0.506
120	-0.474
140	-0.434
160	-0.390
180	-0.340
200	-0.285
220	-0.227
240	-0.166
260	-0.104
280	-0.041

CURVE 2*,‡

T	$\Delta L/L_0$
20.0	-0.543
23.5	-0.543
26.5	-0.543
31.0	-0.542
36.2	-0.542
45.9	-0.540
50.5	-0.539
54.6	-0.538
60.8	-0.535
64.2	-0.533
71.1	-0.528
74.1	-0.526
81.7	-0.519
83.1	-0.518
88.7	-0.511
92.4	-0.507
96.6	-0.501
105.8	-0.488
111.2	-0.479
116.5	-0.470
123.3	-0.458
127.5	-0.450
133.1	-0.439
137.1	-0.431
143.1	-0.418
147.4	-0.408
160.3	-0.378
164.4	-0.368
169.6	-0.356
175.0	-0.342
180.2	-0.329
185.0	-0.316
190.2	-0.302
195.3	-0.289
205.2	-0.262
210.7	-0.246
215.2	-0.233
225.7	-0.203
230.7	-0.189
236.6	-0.171
246.8	-0.141
252.2	-0.124
257.2	-0.109

CURVE 3

T	$\Delta L/L_0$
0	-0.541
20	-0.540
40	-0.537
60	-0.530*
80	-0.518*
100	-0.497*
120	-0.467
140	-0.429*
160	-0.384*
180	-0.334*
200	-0.279*
220	-0.221*
240	-0.161*
260	-0.101*
273.2	-0.061
280	-0.040*
300	0.022

CURVE 4

T	$\Delta L/L_0$
306	0.050
390	0.373
468	0.609
565	0.949
630	1.183
678	1.397
743	1.607
798	1.913
900	2.259

CURVE 5*

T	$\Delta L/L_0$
302.6	0.043
341.1	0.173
381.0	0.315
421.0	0.469
449.0	0.572
481.0	0.708
527.0	0.877

CURVE 6‡

T	$\Delta L/L_0$
273	-0.068*
323	0.102
373	0.277
473	0.646
523	0.839
573	1.039
673	1.459
773	1.904
873	2.375
973	2.874
1023	3.134
1072	3.404
1123	3.689
1173	3.991
1223	4.309

CURVE 7*,‡

T	$\Delta L/L_0$
5.463	-0.548
5.842	-0.548
6.219	-0.548
6.713	-0.548
7.374	-0.548
8.071	-0.548
8.755	-0.548
9.518	-0.548
10.538	-0.548
11.807	-0.548
13.109	-0.548
14.348	-0.548
15.555	-0.548
16.910	-0.548
18.504	-0.548
20.162	-0.548
21.835	-0.548
23.479	-0.548
24.913	-0.548
26.390	-0.548
27.919	-0.548
29.389	-0.548
57.5	-0.541
65.0	-0.537
75.0	-0.529
85.0	-0.519
283.0	-0.032

CURVE 8‡

T	$\Delta L/L_0$
293	0.000
300	0.023*
400	0.374
500	0.773
600	1.216
700	1.700

CURVE 9‡

T	$\Delta L/L_0$
72	-0.539
82	-0.527*
98	-0.505*
111	-0.484
120	-0.468*
146	-0.415
173	-0.351
196	-0.292*
201	-0.278*
224	-0.213
251	-0.132
274	-0.061*
293	0.000*
302	0.029*
327	0.113
376	0.281*
426	0.458
475	0.635*
529	0.837*
553	0.930
579	1.034*

CURVE 10

T	$\Delta L/L_0$
293	0.00
593	1.15

CURVE 11‡

T	$\Delta L/L_0$
134	-0.389
221	-0.208*
273	-0.061*
293	0.000*
315	0.070
409	0.394
479	0.658
491	0.705
569	1.026
666	1.446
736	1.759
759	1.863

CURVE 12*

T	$\Delta L/L_0$
293	0.000
303	0.029
323	0.101
373	0.281
423	0.475
473	0.649
500	0.765

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 291. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM FLUORIDE NaF

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

CURVE 1‡

T	α
40	1.9
50	3.7
60	5.9
70	8.2
80	10.2
90	12.4
100	14.4
120	18.0
140	21.1
160	23.8
180	26.2
200	28.2
220	29.8
240	31.0
260	31.7
280	32.1

CURVE 2‡

T	α
20.0	0.0
23.5	0.4*
26.5	0.4
31.0	0.7*
36.2	1.1
45.9	2.1
50.5	3.0
54.6	3.9
60.8	5.1
64.2	6.0
71.1	7.4
74.1	8.2
81.7	10.0*
83.1	10.4
88.7	12.7
92.4	12.9*
96.6	13.5
105.8	15.5*
111.2	16.6
116.5	17.4*
123.3	18.8
127.5	19.5
133.1	20.3
137.1	21.1*
143.1	21.6
147.4	22.3*
160.3	24.1

CURVE 2 (cont.)‡

T	α
164.4	24.3*
169.6	24.9*
175.0	25.2
180.2	26.1*
185.0	26.4*
190.2	26.9*
195.3	27.0
205.2	27.7*
210.7	28.1*
215.2	28.6*
225.7	29.1
230.7	29.2*
236.6	29.4*
246.8	30.6
252.2	30.4
257.2	30.5

CURVE 6*

T	α
273	33.3
323	34.5
373	35.7
473	38.0
523	39.4
573	40.7
673	43.2
773	45.8
873	48.5
973	51.2
1023	52.7
1072	55.4
1123	58.5
1173	62.3
1223	64.9

CURVE 7‡

T	α
5.463	0.0024
5.842	0.0026*
6.219	0.0019*
6.713	0.0046*
7.374	0.0053*
8.071	0.0071*
8.755	0.0090*
9.518	0.0117*
10.538	0.0161*
11.807	0.0238*

CURVE 7 (cont.)‡

T	α
13.109	0.0316*
14.348	0.0430*
15.555	0.0558*
16.910	0.0715*
18.504	0.0950*
20.162	0.1266*
21.835	0.1643*
23.479	0.2116
24.913	0.2600*
26.390	0.3200*
27.919	0.3900*
29.389	0.4670*
57.5	4.4800
65.0	6.1900*
75.0	8.6700
85.0	11.1200
283.0	31.7300

CURVE 8*,‡

T	α
293	31.9
300	32.7
400	37.6
500	42.2
600	46.4
700	50.3

CURVE 9‡

T	α
72	11.2
82	12.9
98	14.7
111	17.5
120	18.5
146	22.3
173	24.6
196	27.3
201	27.7*
224	29.0*
251	30.5*
274	31.7
293	32.3
302	33.1*
327	33.7*
376	34.9*
426	36.0*
475	36.3*

CURVE 9 (cont.)‡

T	α
529	38.3*
553	39.6*
579	40.5*

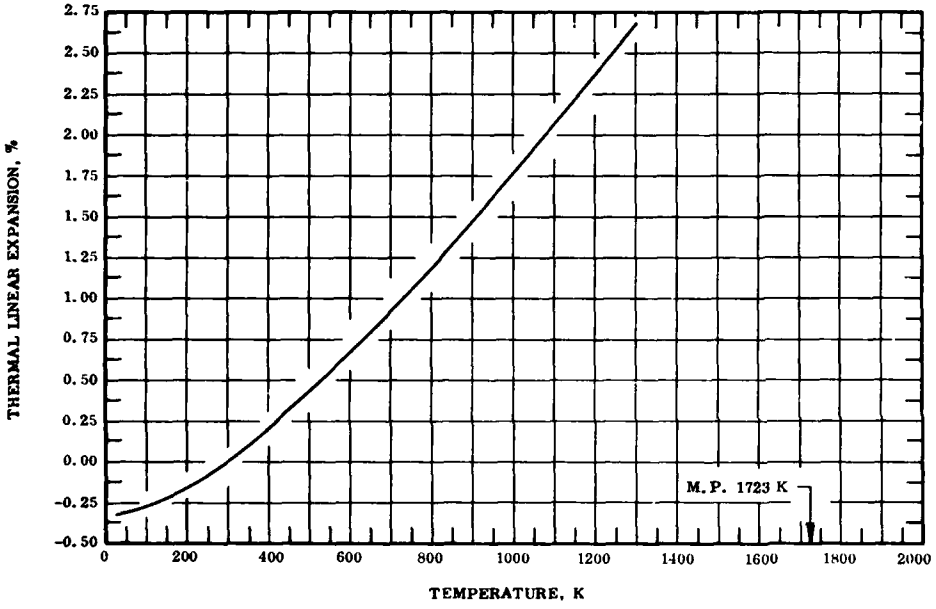
CURVE 11‡

T	α
134	15.3
221	26.3
273	30.2
293	31.3
315	32.4*
409	36.5*
479	38.9*
491	40.3*
569	42.0*
666	44.5*
736	44.9*
759	45.9*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 292R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF STRONTIUM FLUORIDE SrF_2



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
25	-0.316	0.01
35	-0.316	0.6
50	-0.315	1.9
75	-0.306	5.2
100	-0.288	8.4
150	-0.233	13.2
200	-0.160	15.9
250	-0.076	17.1
293	0.000	18.4
350	0.110	19.8
400	0.212	20.9
500	0.430	22.8
600	0.666	24.5
700	0.917	25.9
800	1.182	27.2
900	1.460	28.3
1000	1.750	29.4
1100	2.049	30.3
1200	2.356	31.3
1300	2.670	31.8

REMARKS

The recommended values are based on curve 1 (24-267 K) and curve 2 (297-1275 K) which are consistent with each other and follow the trend for other bromides. These values are considered accurate to within ±5% and can be represented approximately by the following equations:

$$\Delta L/L_0 = -0.306 - 5.941 \times 10^{-4}\, T + 8.898 \times 10^{-6}\, T^2 - 1.133 \times 10^{-8}\, T^3 \qquad (25\text{-}293\ K)$$

$$\Delta L/L_0 = -0.461 + 1.231 \times 10^{-3}\, T + 1.226 \times 10^{-8}\, T^2 - 2.459 \times 10^{-10}\, T^3 \qquad (293\text{-}1300\ K)$$

The tabulated values for the coefficient of thermal expansion below 293 K are based on experimental data. Above 293 K, the values are calculated by differentiating the above equation. These values are considered accurate to about ±7%.

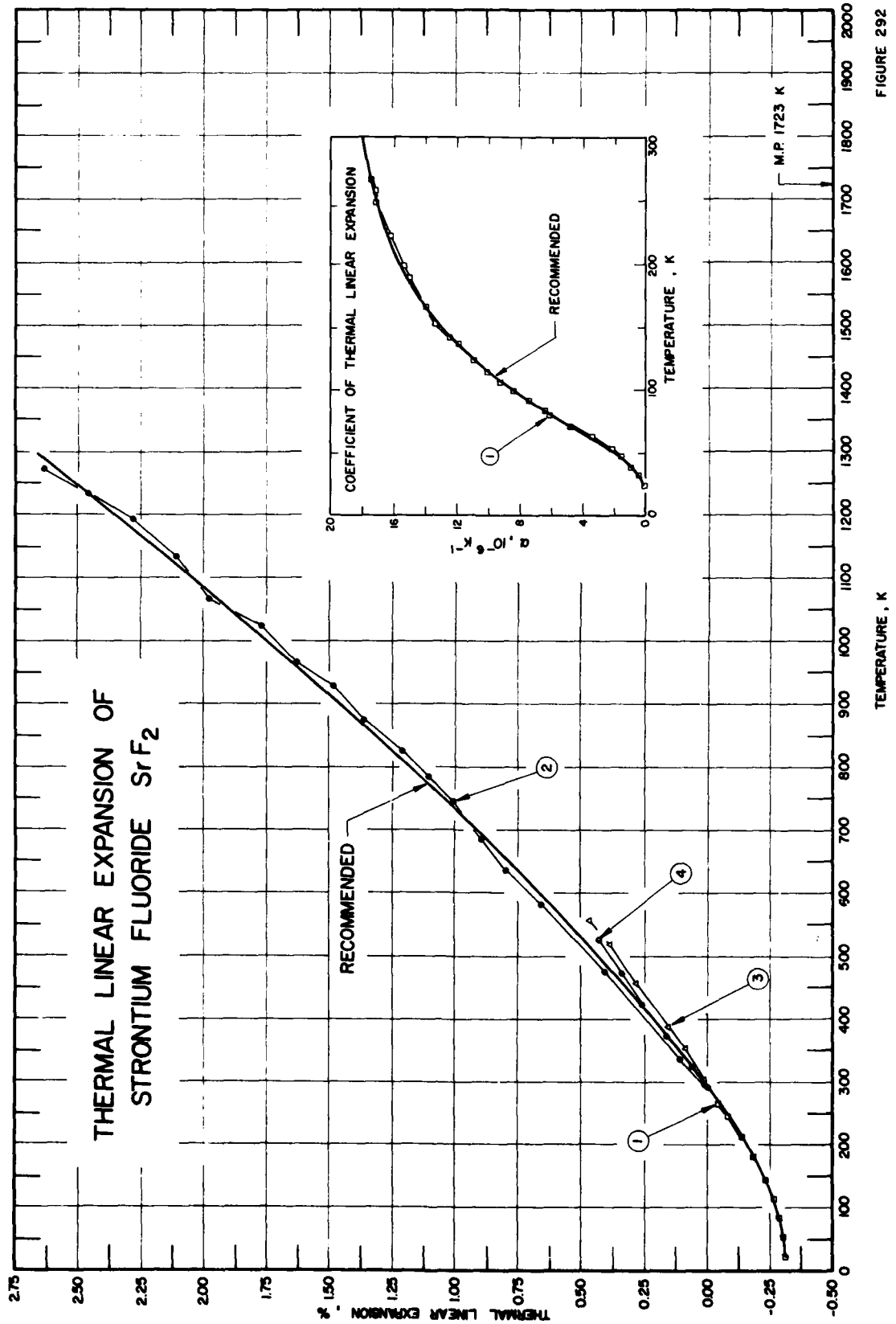

THERMAL LINEAR EXPANSION OF STRONTIUM FLUORIDE SrF_2
RECOMMENDED
M.P. 1723 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
TEMPERATURE , K
$\alpha \cdot 10^{-6} K^{-1}$

FIGURE 292

SPECIFICATION TABLE 292. THERMAL LINEAR EXPANSION OF STRONTIUM FLUORIDE SrF_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	323	Bailey, A. C. and Yates, B.	1967	I	24-267		99.99+ pure; specimen obtained from Koch Light Laboratories; single crystal cut to hollow cylinder 1.8 cm *I.D.*, 2.7 cm *O.D.*, 1.0 cm long.
2	139	Ferguson, I. F., Street, R. S., and D'Eye, R. W. M.	1960	X	297-1275		Crystalline specimen; material obtained from British Drug Houses, heated in argon atm to 1423 K; lattice parameter reported at 297 K as 5.8010 Å; 5.8003 Å at 293 K determined by graphical extrapolation.
3	325	Sirdeskmukh, D. B. and Desphande, V. T.	1964	X	301-557		Lattice parameter reported at 301 K as 5.7982 Å; 5.7974 Å at 293 K determined by graphical extrapolation.
4	791	Murat, M., Chatelut, F., and Bardot, C.	1971	L	293-527	No. 1	Spherical grain size 0.05 μ+ cubes 0.3-0.5 μ; rectangular bar; pulverized powder pressed at 9427 psi; subjected to thermal cycles of 573 K/hr; zero-point correction is 0.012% at 293 K.
5*	791	Murat, M., et al.	1971	L	293-514	No. 2	The above specimen except pressed at 22,335 psi; zero-point correction is 0.007% at 293 K.

* Not shown in figure.

DATA TABLE 292. THERMAL LINEAR EXPANSION OF STRONTIUM FLUORIDE SrF_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 2		CURVE 2 (cont.)		CURVE 4 (cont.)		CURVE 5 (cont.)*	
24	-0.311	126	-0.257*	297	0.011	1232	2.46	323	0.069	404	0.23
32	-0.311*	136	-0.246*	338	0.13	1275	2.63	373	0.167	423	0.14
38	-0.311*	142	-0.238	478	0.41			423	0.251	443	0.14
47	-0.310*	145	-0.234*	581	0.66	CURVE 3		473	0.330	473	0.25
52	-0.309	153	-0.224*	637	0.80			523	0.418*	496	0.34
63	-0.306*	156	-0.220*	683	0.90	301	0.012	527	0.428	514	0.34
71	-0.303*	165	-0.208*	746	1.02	351	0.094				
80	-0.298	180	-0.186	788	1.12	389	0.154	CURVE 5*			
83	-0.296	188	-0.175*	828	1.23	459	0.282				
91	-0.290*	197	-0.161*	871	1.36	520	0.392	293	0.00		
92	-0.289*	212	-0.137	930	1.48	557	0.478	303	0.07		
99	-0.284*	222	-0.121	969	1.63			311	0.31		
107	-0.277*	227	-0.113*	1025	1.77	CURVE 4		323	0.47		
114	-0.270	237	-0.097*	1069	1.98			332	0.59		
116	-0.268*	247	-0.080	1137	2.11	293	0.000	348	0.59		
123	-0.260*	257	-0.062*	1197	2.29	303	0.012*	373	0.41		
		267	-0.045								

DATA TABLE 292. COEFFICIENT OF THERMAL LINEAR EXPANSION OF STRONTIUM FLUORIDE SrF_2

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α
CURVE 1‡		CURVE 1 (cont.)‡	
24	0.0	136	11.9
32	0.4	142	12.5
38	0.9	145	12.6
47	1.5	153	13.3
52	2.1	156	13.4*
63	3.4	165	13.9
71	4.8	180	14.7*
80	6.1	188	15.0
83	6.4	197	15.4
91	7.5	212	15.9*
92	7.8*	222	16.2
99	8.4	227	16.4*
107	9.3	237	16.7*
114	10.1	247	17.2
116	10.4*	257	17.2
123	10.9	267	17.5
126	11.1*		

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

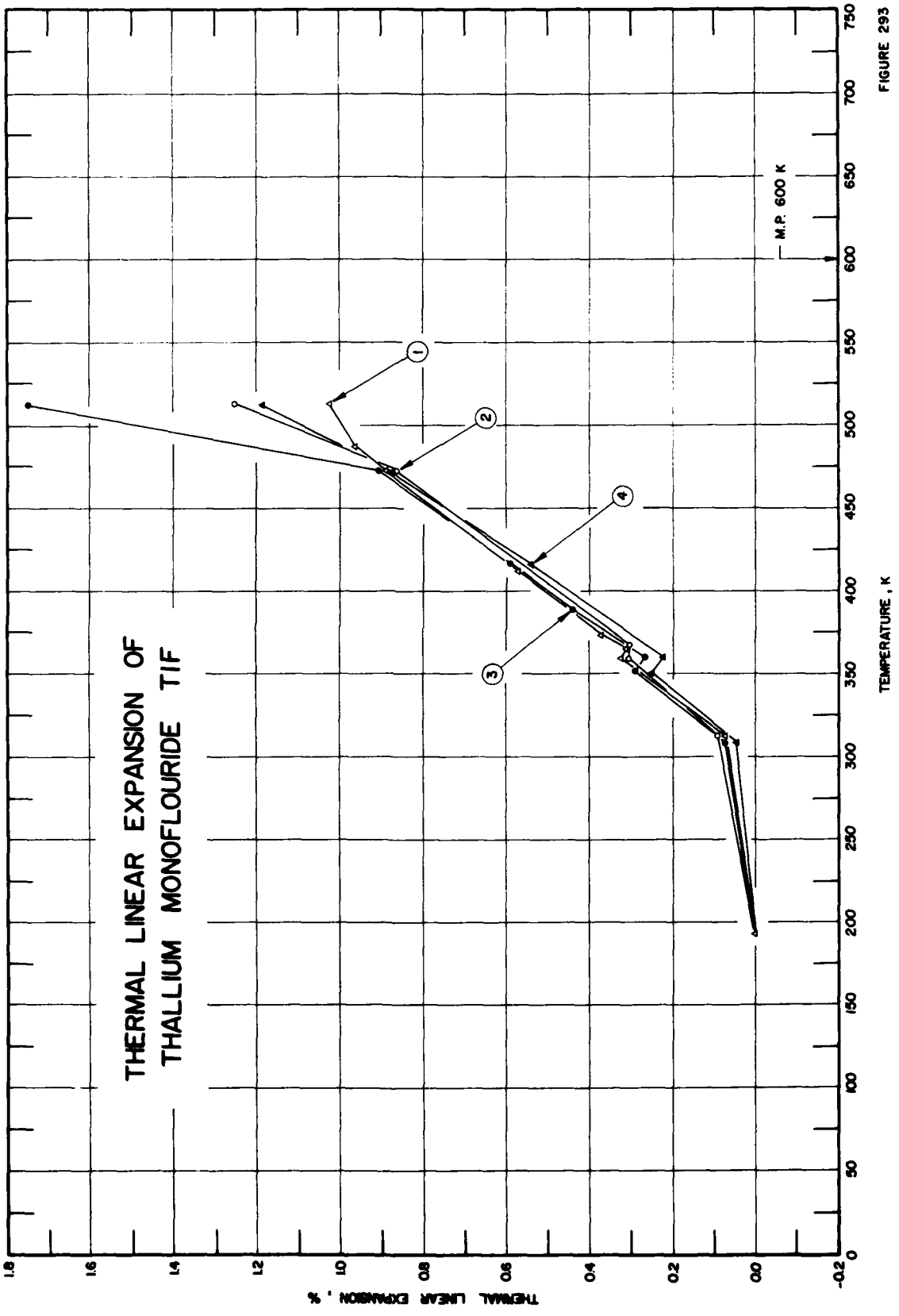

THERMAL LINEAR EXPANSION OF
THALLIUM MONOFLOURIDE TlF
M.P. 600 K
1
2
3
4
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750

FIGURE 293

SPECIFICATION TABLE 293. THERMAL LINEAR EXPANSION OF THALLIUM MONOFLUORIDE TlF

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	791	Murat, M., Chatelut, F., and Bardot, C.	1971	L	293-513		Rectangular bar; pulverized powder pressed at 22,335 psi and subjected to thermal cycles of 573 K/hr; zero-point correction is 0.071% at 293 K; first heating cycle.
2	791	Murat, M., et al.	1971	L	513-293		The above specimen except first cooling cycle; zero-point correction is 0.305% at 293 K.
3	791	Murat, M., et al.	1971	L	293-513		The above specimen except second heating cycle; zero-point correction is 0.070% at 293 K.
4	791	Murat, M., et al.	1971	L	513-293		The above specimen except second cooling cycle; zero-point correction is 0.138% at 293 K.

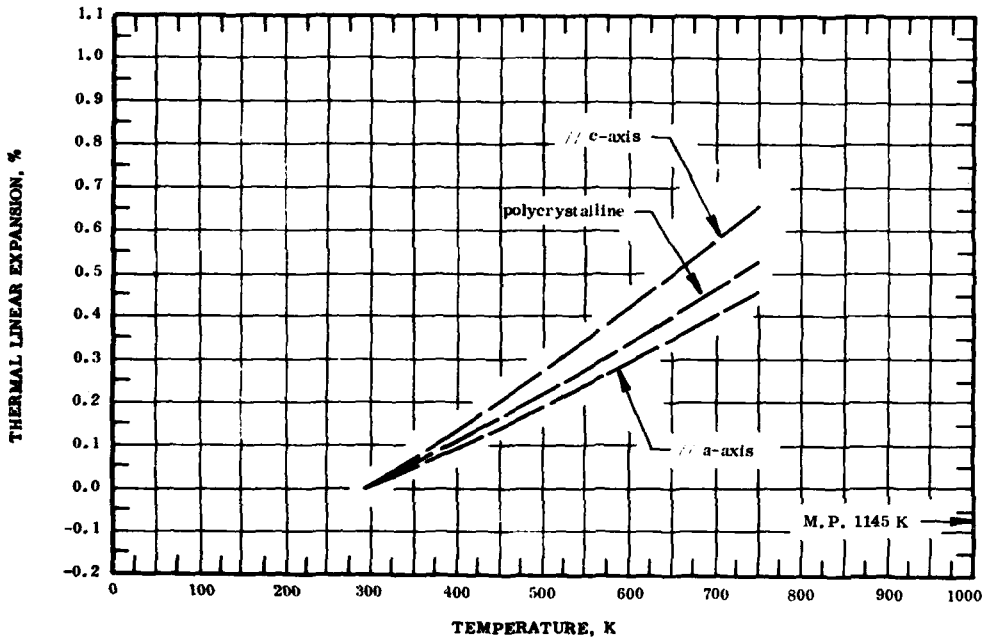
DATA TABLE 293. THERMAL LINEAR EXPANSION OF THALLIUM MONOFLUORIDE TlF

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
313	0.071
359	0.322
365	0.314
373	0.372
413	0.578
473	0.892
487	0.961
513	1.022
CURVE 2	
513	1.256
513	1.224*
473	0.861
367	0.302
358	0.305
CURVE 2 (cont.)	
473	0.861
367	0.302
358	0.305
313	0.095
293	0.000*
CURVE 3	
293	0.000*
308	0.070
351	0.293
360	0.266
389	0.440
416	0.593
473	0.908
513	1.747
CURVE 4	
513	1.185
472	0.874
416	0.540
360	0.223
350	0.252
308	0.045
293	0.000*

* Not shown in figure.

FIGURE AND TABLE NO. 294R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ZINC FLUORIDE ZnF_2



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	9.8
300	0.006	0.008	0.007	9.9
350	0.050	0.071	0.057	10.3
400	0.096	0.136	0.110	10.7
450	0.143	0.205	0.164	11.0
500	0.192	0.275	0.220	11.4
550	0.242	0.348	0.277	11.7
600	0.294	0.422	0.337	12.0
650	0.347	0.498	0.397	12.3
700	0.402	0.574	0.460	12.6
750	0.458	0.651	0.523	12.8

REMARKS

The provisional values for the polycrystalline sample are calculated from the provisional axial data. These values are considered accurate to within ±7% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.227 + 6.845 \times 10^{-4}\ T + 3.073 \times 10^{-7}\ T^2 - 2.363 \times 10^{-12}\ T^3$

// c-axis: $\Delta L/L_0 = -0.276 + 6.360 \times 10^{-4}\ T + 1.199 \times 10^{-6}\ T^2 - 5.322 \times 10^{-10}\ T^3$

polycrystalline: $\Delta L/L_0 = -0.251 + 7.188 \times 10^{-4}\ T + 4.993 \times 10^{-7}\ T^2 - 1.094 \times 10^{-10}\ T^3$

The tabulated values for the coefficient of thermal expansion are calculated primarily by differentiating the above equation for the polycrystalline sample and considered accurate to about ±10%.

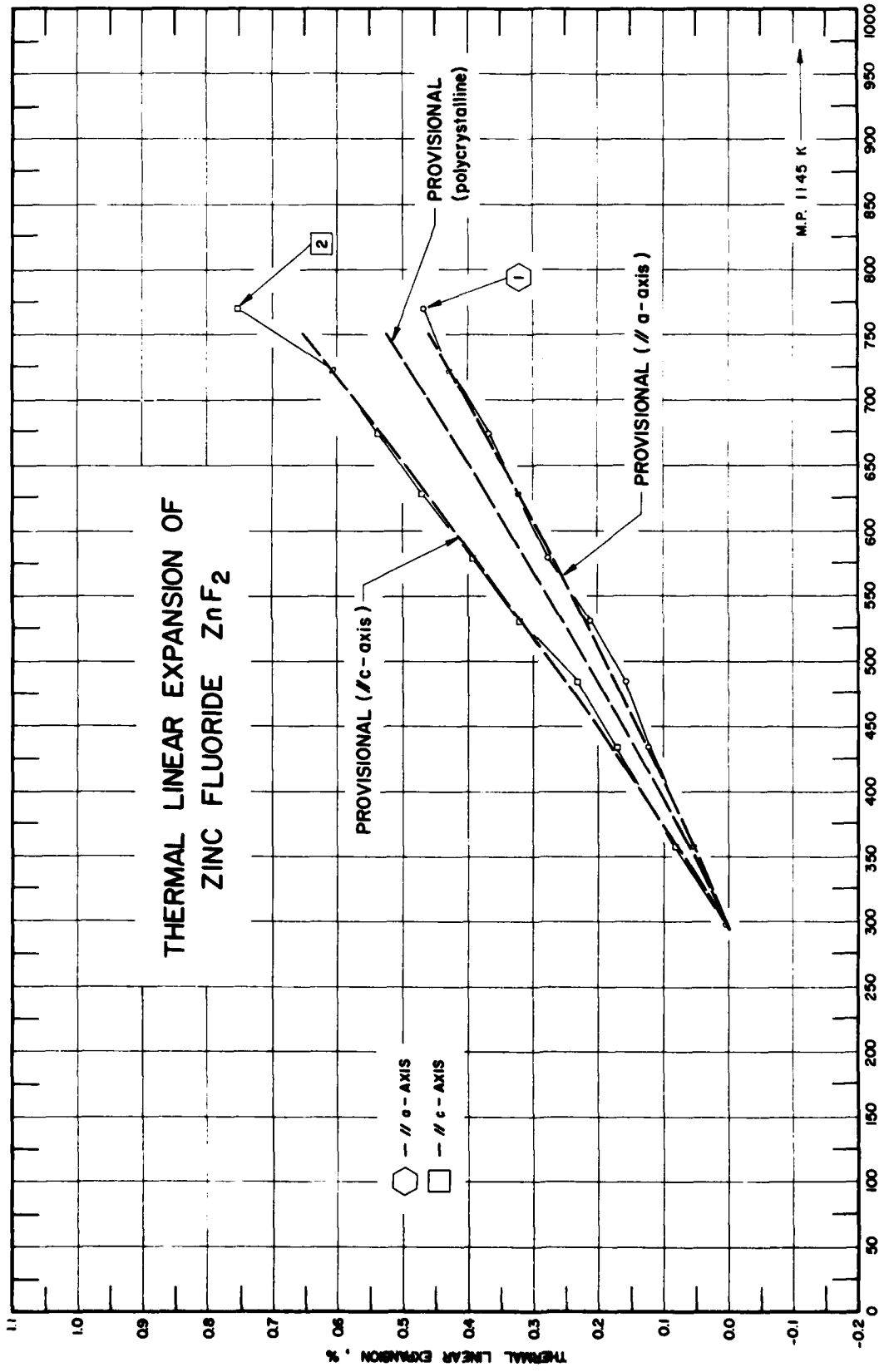

THERMAL LINEAR EXPANSION OF
ZINC FLUORIDE ZnF_2
PROVISIONAL (// c - axis)
PROVISIONAL (polycrystalline)
PROVISIONAL (// a - axis)
M.P. 1145 K
2
1
— // a - AXIS
— // c - AXIS
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 294

SPECIFICATION TABLE 294. THERMAL LINEAR EXPANSION OF ZINC FLUORIDE ZnF_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	*Composition (weight percent), Specifications, and Remarks*
1	781	Rao, K.V.K. and Naidu, S.V.N.	1963	X	297-770		Sample from pure crystal grown from melt, supplied by General Electric Co., N.Y.; expansion of a-cell constant; lattice parameter reported at 297 K as 4.7030 Å; 4.7027 Å at 293 K determined by graphical extrapolation.
2	781	Rao, K.V.K. and Naidu, S.V.N.	1963	X	297-770		The above specimen; expansion of c-cell constant; lattice parameter reported at 297 K as 3.1328 Å; 3.1326 Å at 293 K determined by graphical extrapolation.
3*	782, 783	Rao, K.V.K.	1969	X	298,723		Expansion measured along c-axis.
4*	782, 783	Rao, K.V.K.	1969	X	298,723		The above specimen except expansion measured along a-axis.

DATA TABLE 294. THERMAL LINEAR EXPANSION OF ZINC FLUORIDE ZnF_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
297	0.004
357	0.055
434	0.123
483	0.159
531	0.214
579	0.278
627	0.323
674	0.369
722	0.429
770	0.469
CURVE 2	
297	0.005*
357	0.081
434	0.171
483	0.231
531	0.321
579	0.391
627	0.471
674	0.538
722	0.608
770	0.752
CURVE 3*	
298	0.000
723	0.008
CURVE 4*	
298	0.000
723	0.005

* Not shown in figure.

SPECIFICATION TABLE 295. THERMAL LINEAR EXPANSION OF BARIUM FLUORIDE + CALCIUM FLUORIDE $BaF_2 + CaF_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	148	Ballard, S.S. and Browder, J.S.	1966	I	298, 333	T-12	An optical integral two-phase polycrystalline body consisting of barium fluoride and calcium fluoride in nearly equal molar proportions developed by Harshaw Chemical Company of Cleveland, Ohio; long wavelength transmission limit 12.0 12.0 μ; density 4.35 g/cc, melting temperature 1333 K.

DATA TABLE 295. THERMAL LINEAR EXPANSION OF BARIUM FLUORIDE + CALCIUM FLUORIDE $BaF_2 + CaF_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
298	0.010
333	0.084

* No figure given.

SPECIFICATION TABLE 296. THERMAL LINEAR EXPANSION OF LITHIUM FLUORIDE + NICKEL FLUORIDE $LiF + NiF_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	791	Murat, M., Chatelot, F., and Bardot, C.	1971	L	293-528		0.50 LiF, 0.50 NiF_2; pulverized powder pressed at 1540 bars (22335 psi) and subjected to thermal cycles of 573 K/hr; zero-point correction is 0.024% at 293 K; heating cycle.
2*	7	Murat, M., et al.	1971	L	528-293		The above specimen except cooling cycle; zero-point correction is 0.029% at 293 K.
3*	7	Murat, M., et al.	1971	L	293-528		Similar to the above specimen except 0.85 NiF_2, 0.15 LiF_2; heating cycle, zero-point correction 0.029% at 293 K.
4*	7	Murat, M., et al.	1971	L	527-293		The above specimen; cooling cycle; zero-point correction 0.029% at 293 K.

DATA TABLE 296. THERMAL LINEAR EXPANSION OF LITHIUM FLUORIDE + NICKEL FLUORIDE $LiF + NiF_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*		CURVE 3*		CURVE 4 (cont.)*	
293	0.000	528	0.497	293	0.000	439	0.465
301	0.024	524	0.467	306	0.029	423	0.392
323	0.102	511	0.422	323	0.100	373	0.216
343	0.156	494	0.378	373	0.277	323	0.074
373	0.225	478	0.337	423	0.454	306	0.029
386	0.267	460	0.299	436	0.503	293	0.000
413	0.318	444	0.264	444	0.517		
430	0.347	434	0.248	473	0.598		
442	0.366	421	0.206	528	0.764		
458	0.403	406	0.167				
472	0.426	387	0.140	CURVE 4*			
490	0.455	373	0.111				
505	0.475	352	0.082	527	0.764		
528	0.492	323	0.045	505	0.666		
		293	0.000	473	0.546		

* No figure given.

SPECIFICATION TABLE 297. THERMAL LINEAR EXPANSION OF MISCELLANEOUS FLUORIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	148	Ballard, S.S. and Browder, J.S.	1966	I	298-333	CdF_2	Cadmium fluoride; single crystal, produced by Harshaw Chemical Co. of Cleveland, Ohio; reported error < 2.0%.
2*	630	Ballard, S.S., Browder, J.S., Kaylor, H.M., and Streete, J.L.	1967	I	276-326	CdF_2	Cadmium fluoride; single crystal specimen.
3*	780	Krukowska-Fulde, B. and Niemyski, T.	1967	L	296-723	CdF_2	Cadmium fluoride; cylindrical specimen 11 mm diameter x 120 mm long; single crystal grain by the modified Bridgman-Stockbarger; in oxygen free nitrogen atm heated in vacuum to 973 K; nitrogen flowed during growth of crystals at 770 mm; liquid zone passed at 20-30 m/h; annealed at 1073 K; cooled at 50 C/hr; weight 65 gm.
4*	623	White, G.K. and Collins, J.C.	1973	E	3-283	CsF	Cesium fluoride; cylindrical specimen 20 mm diameter x 50.8 mm long; obtained from Harshaw Chemical Co. of Ohio; data reported was smoothed; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
5*	632	Bridgman, P.W.	1932		303, 348	CsF	Cesium fluoride; cylindrical specimen 9.5 mm diameter x 9.5-12.7 mm long; specimen made by pressing; expansion measured using lever piezometer.
6*	781	Rao, K.V.K. and Naidu, S.V.N.	1963	X	307-844	CoF_2	Cobalt fluoride; sample from pure crystal grown from melt, supplied by General Electric Co., N.Y.; expansion measured along a-axis; lattice parameter reported at 307 K as 4.6954 Å; 4.6949 Å at 293 K determined by graphical extrapolation; lattice parameter reported at 298 K as 4.6952 Å.
7*	781	Rao, K.V.K. and Naidu, S.V.N.	1963	X	307-844	CoF_2	Cobalt fluoride; the above specimen; expansion measured along c-axis; lattice parameter reported at 307 K as 3.1774 Å; 3.1773 Å at 293 K determined by graphical extrapolation; error in reported data at 844 K; lattice parameter reported as 4.1918 Å; TPRC believes data was actually 3.1918 Å; lattice parameter reported at 298 K as 3.1171 Å.
8*	782	Rao, K.V.K.	1969	X	298, 803	CoF_2	Cobalt fluoride; expansion measured along c-axis.
9*	782	Rao, K.V.K.	1969	X	298, 803	CoF_2	Cobalt fluoride; the above specimen except expansion measured along a-axis.
10*	663	Von Trost, K.F.	1963		131-293	RbF	Rubidium fluoride; no details given.
11*	794	Teaney, D.T., Moruzzi, V.L., and Argyle, B.E.	1966	X	31-297	$RbMnF_3$	Rubidium manganese trifluoride; expansion measured along crystal a-axis.
12*	795	Pistorius, C.W.F.T., Boeyens, J.C.A., and Clark, J.B.	1969	X	299-584	$NaBF_4$	Sodium tetrafluoroborate; powder pattern from Hopkin & Williams Ltd.; thoroughly dried before use, measured by using filtered CuKα radiation; sample contained in sealed Lindemann tubes mounted in Weissenberg camera, and heated by stream of hot nitrogen; measured in a_0-axis of unit-cell dimension; lattice parameter reported at 299 K as 6.864 Å; 6.862 Å at 293 K determined by graphical extrapolation; phase transition reported at 543 K.
13*	795	Pistorius, C.W.F.T., et al.	1969	X	299-584	$NaBF_4$	Sodium tetrafluoroborate; the above specimen; measured in b_0-axis of unit-cell dimension; lattice parameter reported at 299 K as 6.328 Å; 6.326 Å at 293 K determined by graphical extrapolation; phase transition reported at 543 K.
14*	795	Pistorius, C.W.F.T., et al.	1969	X	299-584	$NaBF_4$	Sodium tetrafluoroborate; the above specimen; measured in c_0-axis of unit-cell dimension; lattice parameter reported at 299 K as 6.808 Å; 6.807 Å at 293 K determined by graphical extrapolation; phase transition reported at 543 K.

* No figure given.

DATA TABLE 297. THERMAL LINEAR EXPANSION OF MISCELLANEOUS FLUORIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
298	0.011
333	0.088

CURVE 2*, ‡

T	$\Delta L/L_0$
276	-0.036
278	-0.032
282	-0.023
288	-0.009
293	-0.000
293	0.001
298	0.012
304	0.025
307	0.031
309	0.036
314	0.047
318	0.054
323	0.065
326	0.072

CURVE 3*

T	$\Delta L/L_0$
296	0.000
273	0.104
473	0.351
573	0.784
673	1.121
723	1.290

CURVE 4*, †, ‡

T	$\Delta L/L_0$
3	0.0000×10^{-3}
4	0.0002
5	0.0009
6	0.0023
7	0.0054
8	0.0117
9	0.0232
10	0.0431
12	0.1201
14	0.2641
16	0.4961
18	0.8271
20	1.2631
22	1.8111
24	2.4771

CURVE 4 (cont.)*, †, ‡

T	$\Delta L/L_0$
26	3.2661×10^{-3}
28	4.1821
30	5.2271
57	33.0021
65	45.0021
75	63.2971
85	83.5921
283	630.0721

CURVE 5*

T	$\Delta L/L_0$
303	0.0317
348	0.1744

CURVE 6*

T	$\Delta L/L_0$
307	0.004
357	0.042
434	0.134
483	0.185
531	0.256
579	0.343
627	0.362
674	0.454
722	0.547
770	0.560
807	0.656
844	0.709

CURVE 7*

T	$\Delta L/L_0$
307	0.004
357	0.020
434	0.079
483	0.092
531	0.130
579	0.183
627	0.196
674	0.231
722	0.291
770	0.325
807	0.388
844	0.458

CURVE 8*

T	$\Delta L/L_0$
298	0.001
803	0.632

CURVE 9*

T	$\Delta L/L_0$
298	0.005
803	0.805

CURVE 10*, ‡

T	$\Delta L/L_0$
131	-0.392
179	-0.292
263	-0.081
293	0.000

CURVE 11*

T	$\Delta L/L_0$
31	-0.298
47	-0.293
51	-0.290
53	-0.304
64	-0.287
66	-0.281
76	-0.286
96	-0.268
111	-0.263
125	-0.249
154	-0.222
189	-0.185
224	-0.142
252	-0.082
281	-0.034
297	0.002

CURVE 12*

T	$\Delta L/L_0$
299	0.027
414	0.537
508	0.959

T	a (Å)
543	5.8
584	5.751

CURVE 13*

T	$\Delta L/L_0$
299	0.029
414	0.582
508	1.704

T	b (Å)
543	8.100
584	8.165

CURVE 14*

T	$\Delta L/L_0$
299	0.004
414	0.092
508	0.563

T	c (Å)
543	7.100
584	7.132

* No figure given.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 297. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS FLUORIDES

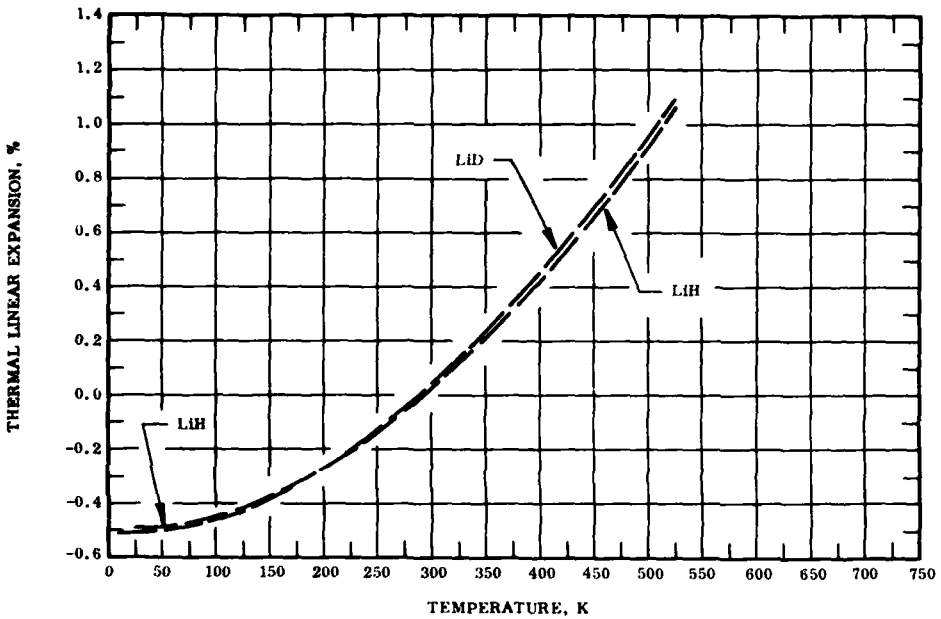
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 2*,‡	
276	21.23
278	21.28
282	21.38
288	21.28
293	21.54
293	21.30
298	21.44
304	21.83
307	21.79
309	22.03
314	21.89
318	22.07
323	22.07
326	21.99
CURVE 4*,‡	
3	0.001
4	0.004
5	0.009
6	0.020
7	0.042
8	0.083
9	0.148
10	0.250
12	0.520
14	0.920
16	1.400
18	1.910
20	2.450
22	3.030
24	3.630
26	4.260
28	4.900
30	5.550
57	14.650
65	17.350
75	19.240
85	21.350
283	33.850
CURVE 10*,‡	
131	17.9
179	23.5
263	26.8
293	27.2

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 298R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF LITHIUM HYDRIDE AND LITHIUM DEUTERIDE LiH, LiD



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	LiH		LiD	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
10			-0.509	0.01
25	-0.494	0.5	-0.510	0.6
50	-0.492	0.3	-0.506	3.1
75	-0.479	5.9	-0.492	7.2
100	-0.456	10.6	-0.469	11.0
150	-0.383	19.1	-0.395	18.3
200	-0.275	24.8	-0.287	24.9
250	-0.138	29.8	-0.146	31.4
293	0.000	34.1	0.000	36.7
300	0.024	34.5	0.026	37.7
325	0.114	37.2	0.124	40.3
350	0.210	39.7	0.228	42.6
375	0.312	42.3	0.337	44.8
400	0.421	45.0	0.451	46.8
425	0.537	47.6	0.571	48.6
450	0.660	50.3	0.694	50.2
475	0.789	53.0	0.821	51.6
500	0.925	55.7	0.952	52.8
525	1.067	58.5	1.085	53.9

REMARKS

The provisional values for LiH and LiD are considered accurate to within ± 10% and are represented approximately by the following equations:

LiH: $\Delta L/L_0 = -0.486 - 5.677 \times 10^{-4}\ T + 9.185 \times 10^{-6}\ T^2 - 5.396 \times 10^{-9}\ T^3$ (25-293 K)

$\Delta L/L_0 = -0.554 + 4.346 \times 10^{-4}\ T + 4.868 \times 10^{-6}\ T^2 + 3.553 \times 10^{-10}\ T^3$ (293-525 K)

LiD: $\Delta L/L_0 = -0.506 - 3.917 \times 10^{-4}\ T + 7.823 \times 10^{-6}\ T^2 - 2.034 \times 10^{-9}\ T^3$ (10-293 K)

$\Delta L/L_0 = -0.498 - 7.254 \times 10^{-4}\ T + 9.733 \times 10^{-6}\ T^2 - 4.965 \times 10^{-9}\ T^3$ (293-525 K)

The tabulated values for the coefficient of thermal expansion are derived primarily by differentiating the above equations and are considered accurate to about ± 10% at temperatures above 293 K and ± 15% below 293 K.

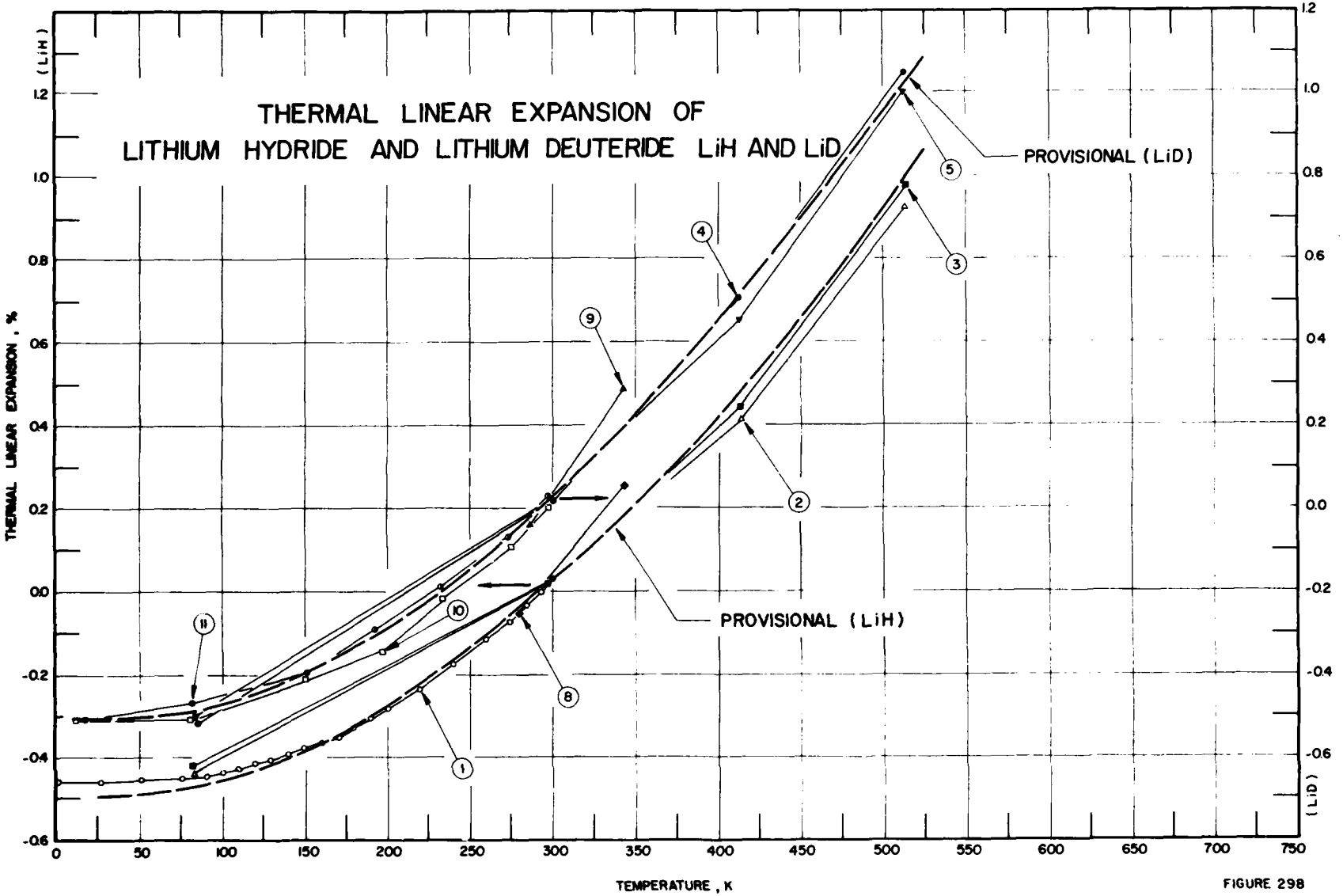

THERMAL LINEAR EXPANSION OF
LITHIUM HYDRIDE AND LITHIUM DEUTERIDE LiH AND LiD
PROVISIONAL (LiD)
PROVISIONAL (LiH)
THERMAL LINEAR EXPANSION, % (LiH)
(LiD)
TEMPERATURE, K
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
1
2
3
4
5
8
9
10
11

FIGURE 298

SPECIFICATION TABLE 298. THERMAL LINEAR EXPANSION OF LITHIUM HYDRIDE AND LITHIUM DEUTERIDE LiH and LiD

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	798	Laquer, H. L.	1952	L	0-300	LiH	Final dimensions: cylindrical rod; 0.5 cm diameter x 1.27-2.54 cm long; prepared by pressing 20 mesh size powder at 673 K and 1406 kg cm^{-2} in aquadog lubricated steel mold for 3 min into 1.27 cm diameter x 2.54-3.81 cm long pellets; then cooled in situ at 473 K for 30 min; transferred in air to CaCl dessicator; machined to final dimensions; reported error ± 10%; data extracted is a smooth curve drawn by author through expansion values of four samples (which differed only in their dimensions).
2	1099	Anderson, J. L., Nasise, J., Philipson, K., and Pretzel, F. E.	1969		83-513	Li^6H	Prepared by F.E. Pretzel (Amer. Chem. Soc. Abstracts, Southwest Regional Meeting, Austin Texas 1968); x-ray method used from 83 K to 298 K; a floatation method used from 298 to 513 K densities were measured and then converted to lattice parameters.
3	1099	Anderson, J. L., et al.	1969		83-513	Li^7H	Similar to the above except different isotope of Li.
4	1099	Anderson, J. L., et al.	1969		85-513	Li^7D	Similar to the above except different isotope of Li.
5	1099	Anderson, J. L., et al.	1969		83-513	Li^6D	Prepared by and purchased from Y-12 Plant, Oak Ridge, Tenn.; recrystallized and annealed in device for growing crystals.
6*	1100	Kogan, V.S. and Omarov, T.G.	1965		78,300	LiH	Cylindrical specimen, 1.5 mm diameter; prepared from pure elements; lithium heated to 973 K in hydrogen gas.
7*	1100	Kogan, V.S. and Omarov, T.G.	1965		78,300	LiD	Similar to the above except lithium heated in deuterium.
8	786	Baikov, Y.M., Ryskin, G.Ya., Stepanov, Yu.P., Subashiev, A.V., Karenblit, I.Ya., and Klochikin, A.A.	1969		281,342	LiH	Crystal shape, 2 to 4 mm size; hydride prepared by direct contact of hydrogen on lithium (which was cleaned of impurities at 973 K); expansion determined by floatation method; sample floated in cycle hexane + benzene; reported density 0.7773 g cm^3.
9	786	Baikov, Y.M., et al.	1969		286,342	LiD	Similar to the above except floatation liquid was benzene + toluene and ethylene bromide; reported density 0.8841 g cm^3.
10	587	Smith, D.K. and Leider, H.R.	1968	X	12-298	Li^6D	0.05 to 0.1 each C, N, O, 0.006 Na, 0.0003 Mg; prepared by hydriding molten Li metal at 503 K in iron crucible; heated to 1023 K for 1 hr; then cooled at 25 C/hr; several large crystals were formed and cleaved (on (100) plane) to make specimen; expansion method was low temperature x-ray cryostat.
11	587	Smith, D.K. and Leider, H.R.	1968	X	15-299	Li^7D	Similar to the above except different composition.

* No figure given.

DATA TABLE 298. THERMAL LINEAR EXPANSION OF LITHIUM HYDRIDE AND LITHIUM DEUTERIDE LiH and LiD

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
0	-0.460
25	-0.460
50	-0.457
75	-0.450
90	-0.444
100	-0.436
110	-0.428
120	-0.418
130	-0.406
140	-0.393
150	-0.378
160	-0.362
170	-0.345
180	-0.324
190	-0.303
200	-0.280
220	-0.232
240	-0.176
260	-0.114
275	-0.071
285	-0.032
293	0.000
300	0.029
CURVE 2	
83	-0.440
298	0.012
413	0.409
513	0.911
CURVE 3	
83	-0.412
298	0.010
413	0.441
513	0.977
CURVE 4	
85	-0.519
298	0.012
413	0.504
513	1.059
CURVE 5	
83	-0.501
298	0.012*
413	0.455
513	1.000
CURVE 6*	
78	-0.448
300	0.017
CURVE 7*	
78	-0.516
300	0.025
CURVE 8	
281	-0.062
342	0.255
CURVE 9	
286	-0.042
342	0.296
CURVE 10	
12.1	-0.514
80	-0.514
152	-0.415
195	-0.342
235	-0.219
275	-0.096
298	0.002
CURVE 11	
15.7	-0.492
81	-0.467
152	-0.393
193	-0.295
233	-0.197
272	-0.074
299	0.025

* No figure given.

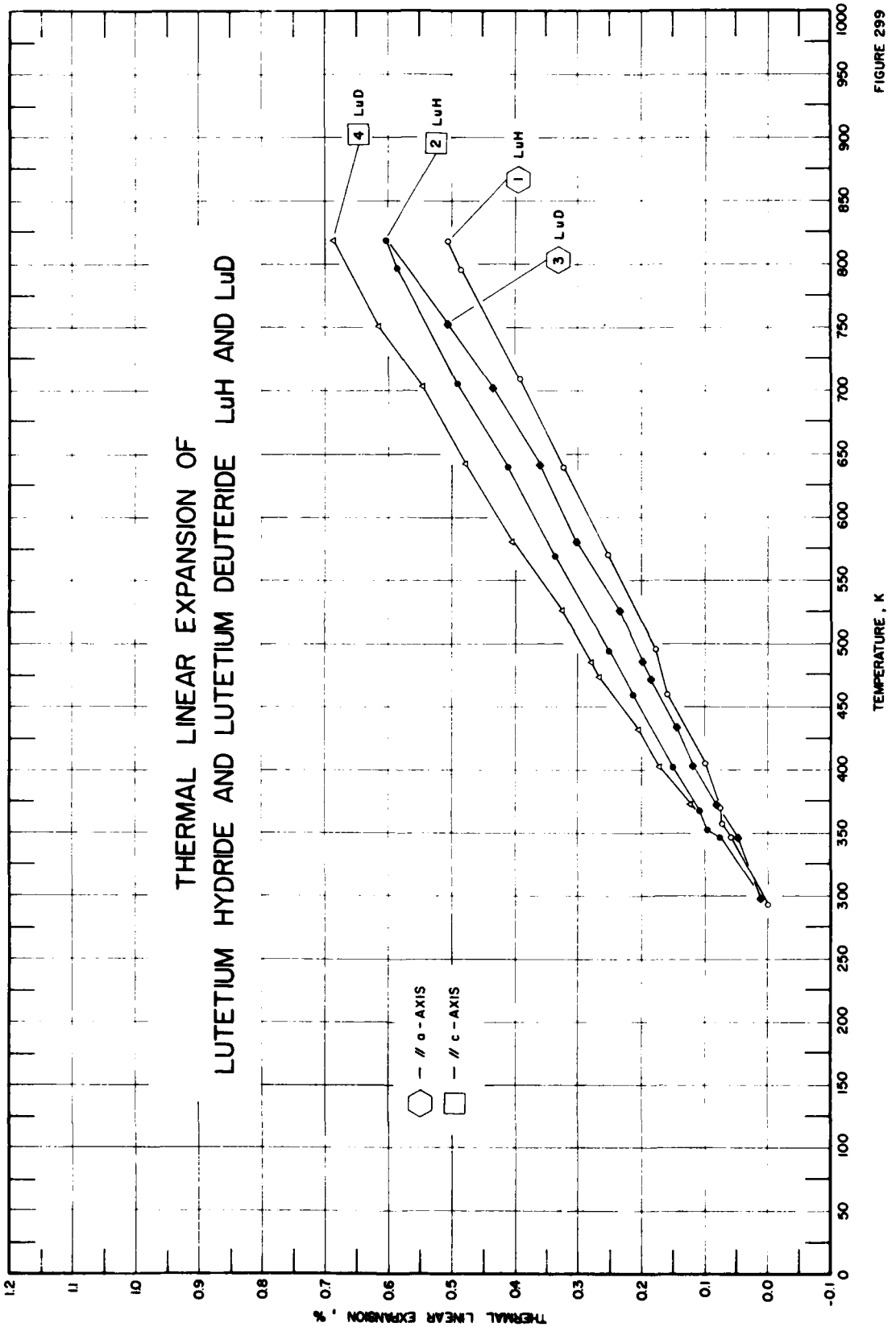

THERMAL LINEAR EXPANSION OF
LUTETIUM HYDRIDE AND LUTETIUM DEUTERIDE LuH AND LuD
4 LuD
2 LuH
1 LuH
3 LuD
// a - AXIS
// c - AXIS
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K

FIGURE 299

SPECIFICATION TABLE 299. THERMAL LINEAR EXPANSION OF LUTETIUM HYDRIDE AND LUTETIUM DEUTERIDE LuH and LuD

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1101	Daou, J.N. and Bonnet, J.E.	1972	X	293-818	$LuH_{0.2}$	Strip size; 0.2 x 0.5 x 15 mm long; Lu metal obtained from Johnson and Matthey (impurities < 0.05); annealed at 1073 K for 10 hr; surface cleaned; hydrogenerated by successive additions of small amounts of hydrogen at 823 K; formed into powder strip and placed in capillary tube and sealed in vacuum; expansion measured along a-axis; lattice parameter reported at 295 K as 3.5253 Å; 3.5250 Å at 293 K determined by graphical extrapolation.
2	1101	Daou, J.N. and Bonnet, J.E.	1972	X	293-818	$LuH_{0.2}$	Same as the above; expansion measured along c-axis; lattice parameter reported at 295 K as 5.6079 Å; 5.6077 Å at 293 K determined by graphical extrapolation.
3	1101	Daou, J.N. and Bonnet, J.E.	1972	X	293-820	$LuD_{0.19}$	Similar to the above; different composition; expansion measured along a-axis; lattice parameter reported at 299 K as 3.5218 Å; 3.5213 Å at 293 K determined by graphical extrapolation.
4	1101	Daou, J.N. and Bonnet, J.E.	1972	X	293-818	$LuD_{0.19}$	Similar to the above; different composition; expansion measured along c-axis; lattice parameter reported at 299 K as 5.6037 Å; 5.6033 Å at 293 K determined by graphical extrapolation.

DATA TABLE 299. THERMAL LINEAR EXPANSION OF LUTETIUM HYDRIDE AND LUTETIUM DEUTERIDE LuH and LuD

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3		CURVE 4	
293	0.000	293	0.000	293	0.000	293	0.000
295	0.009*	295	0.004	299	0.014	299	0.007
347	0.060	347	0.077	347	0.048	345	0.077
356	0.071	354	0.095	373	0.080	372	0.123
370	0.078	368	0.109	402	0.119	402	0.171
406	0.099	407	0.150	433	0.145	433	0.209
460	0.159	460	0.214	472	0.187	474	0.269
495	0.179	495	0.251	486	0.199	485	0.280
570	0.252	570	0.335	527	0.236	526	0.327
639	0.321	640	0.412	581	0.301	580	0.403
710	0.394	712	0.490	641	0.361	642	0.478
797	0.485	798	0.585	702	0.437	702	0.548
818	0.505	818	0.601	752	0.508	752	0.614
				820	0.602*	818	0.687

* Not shown in figure.

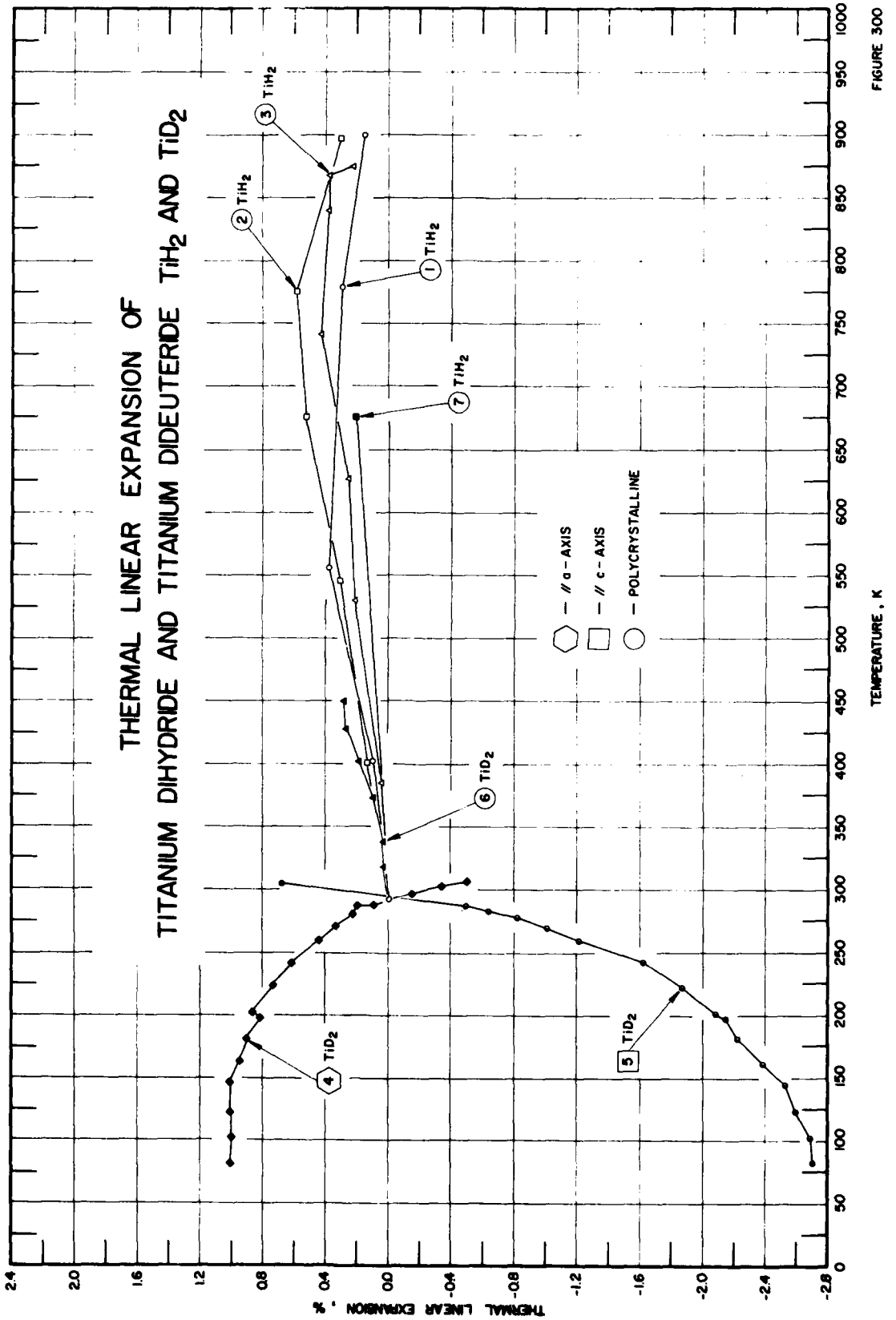

THERMAL LINEAR EXPANSION OF
TITANIUM DIHYDRIDE AND TITANIUM DIDEUTERIDE TiH_2 AND TiD_2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.4
2.0
1.6
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
-1.6
-2.0
-2.4
-2.8
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
① TiH_2
② TiH_2
③ TiH_2
④ TiD_2
⑤ TiD_2
⑥ TiD_2
⑦ TiH_2
— // a - AXIS
— // c - AXIS
— POLYCRYSTALLINE

FIGURE 300

SPECIFICATION TABLE 300. THERMAL LINEAR EXPANSION OF TITANIUM DIHYDRIDE AND TITANIUM DIDEUTERIDE TiH_2 and TiD_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1102	Goon, E.J. and Malgiolo, J.	1958	X	293-900	TiH_2	fcc structure; prepared from high purity Ti (3 types of Ti metal used; Na reduced T_1 crystals from National Distillers; sheet metal from the Alloy Division of the National Lead Co., and drip melt metal from Nuclear Metals); etched in solution of 5% HF, 45% HNO_3, and 50% H_2O in polyethylene until surface lustrous, washed with indistilled water, isopropyl alcohol and anhydrous; quickly weighed in air; re-etched and washed as before; placed in Vycor tube containing argon gas on a stainless steel boat; hydriding by heating sample until first sign H pickup occurred; temperature increased to 100 K and kept constant until absorption complete; expansion measured at 7-7.2 kg/cm^2; lattice parameter reported at 293 K as 4.442 Å.
2	1102	Goon, E.J. and Malgiolo, J.	1958	X	293-895	TiH_2	Same as the above specimen; expansion measured at 19-19.7 kg/cm^2; lattice parameter reported at 293 K as 4.437 Å.
3	1102	Goon, E.J. and Malgiolo, J.	1958	X	293-873	TiH_2	Same as the above specimen; expansion measured at 30-31 kg/cm^2; lattice parameter reported at 293 K as 4.437 Å.
4	1103	Yakel, H.L.	1957	X	83-306	$TiD_{1.98}$	Prepared by placing metal Ti in Mo boat and heating to 1273 K in a vacuum; H entered vacuum at 1273 K and 1 atm pressure; then cooled to 673 K and kept constant for several hr; then H gas evacuated and sample heated to 1273 K; purified H gas entered vacuum at 1 atm pressure; then cooled to 293 K; expansion measured along a-axis.
5	1103	Yakel, H.L.	1957	X	83-308	$TiD_{1.98}$	The above specimen; expansion measured along c-axis.
6	1103	Yakel, H.L.	1957	X	317-450	$TiD_{1.98}$	Similar to the above specimen; cubic structure; lattice parameter reported at 317 K as 4.438 Å; 4.437 Å at 293 K determined by graphical extrapolation.
7	1104, 1105	Baromtseva, I.G. and Antonova, M.M.	1969	L	293,673	$TiH_{1.92}$	96.03 Ti, 3.87 H; compact sample; metal Ti cold pressed at 1143 K for 1 hr at 10^{-3} torr into briquettes; then cooled to 873 K when H gas entered at 100 cm^3/min for 7 min; reported density 2.73-2.95 gm/cm^3; porosity 23-24%.

DATA TABLE 300. THERMAL LINEAR EXPANSION OF TITANIUM DIHYDRIDE AND TITANIUM DIDEUTERIDE TiH_2 and TiD_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
401	0.090
553	0.383
779	0.293
900	0.135
CURVE 2	
293	0.000*
401	0.113
545	0.316
676	0.518
777	0.473
895	0.293
CURVE 3	
293	0.000*
385	0.045
532	0.203
628	0.248
741	0.428
840	0.338
864	0.338
873	0.225
CURVE 4	
83	1.074
103	1.074
124	1.074
142	1.030
162	0.940
182	0.895
198	0.806
201	0.850
222	0.739
241	0.604
260	0.448
270	0.336
280	0.224
286	0.201
286	0.090
293	0.000*
297	-0.179
301	-0.358
306	-0.492
CURVE 5	
83	-2.780
101	-2.689
122	-2.597
142	-2.529
161	-2.392
182	-2.210
197	-2.142
200	-2.073
222	-1.868
243	-1.618
260	-1.208
269	-1.025
277	-0.820
283	-0.684
286	-0.501
293	-0.159
293	0.000*
297	0.000
308	0.684
CURVE 6	
317	0.023
337	0.023
374	0.090
407	0.180
429	0.225
450	0.248
CURVE 7	
293	0.000*
673	0.201

* Not shown in figure.

SPECIFICATION TABLE 301. THERMAL LINEAR EXPANSION OF TITANIUM MONOHYDRIDE TiH

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	1106	Van Houten, R. and Baxter, W.G.	1964		293-764		3.12 H ; cylindrical specimen, 9 cm diameter x 21 cm long; hydrided to N_H = 7.27 ($N_H = 7.27 \times 10^{23}$ atoms/cm^3) ; reported density 3.87 g cm^3; zero-point correction -0.014% .

DATA TABLE 301. THERMAL LINEAR EXPANSION OF TITANIUM MONOHYDRIDE TiH

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
373	0.053
451	0.119
518	0.189
599	0.280
668	0.372
764	0.509

* No figure given.

SPECIFICATION TABLE 302. THERMAL LINEAR EXPANSION OF VANADIUM HYDRIDE VH

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	1107	Maeland, A.J.	1964	X	293-582	$VH_{0.15}$	Prepared by etching 0.1-0.6 mole of V metal in 5% HF-15% NO_3 followed by two tinses each in water, isopropylalcohol and anhydrous ether; then placed in stainless steel boat inside quartz tube; quartz tube evacuated to 10^{-6} Torr and heated to 973 K; then cooled to 673 K; purified hydrogen at 1 atm was allowed to react; then cooled to 293 K; hydride crushed to 325 mesh size powder and above process repeated to 973 K and 10^{-6} Torr; hydride was reacted with hydrogen at 293 K to form the specimen; then homogenized at 573 K for 2-5 hr by vibrating quartz tube; lattice parameter reported at 290 K as 3.0366 Å; 3.0357 Å at 293 K determined by graphical extrapolation.
2*	1107	Maeland, A.J.	1964	X	373-597	$VH_{0.3}$	Similar to the above specimen; different composition; lattice parameter reported at 373 K as 3.055 Å; this curve is here reported using the first given temperature 373 K as the reference temperature at which $\Delta L/L_0 = 0$.
3*	1107	Maeland, A.J.	1964	X	470-596	$VH_{0.37}$	Similar to the above specimen; different composition; lattice parameter reported at 470 K as 3.1019 Å; this curve is here reported using the first given temperature 470 K as the reference temperature at which $\Delta L/L_0 = 0$.
4*	1107	Maeland, A.J.	1964	X	477-585	$VH_{0.43}$	Similar to the above specimen; different composition; lattice parameter reported at 477 K as 3.1135 Å; this curve is here reported using the first given temperature 477 K as the reference temperature at which $\Delta L/L_0 = 0$.
5*	1107	Maeland, A.J.	1964	X	459-588	$VH_{0.58}$	Similar to the above specimen; different composition; lattice parameter reported at 459 K as 3.1457 Å; this curve is here reported using the first given temperature 459 K as the reference temperature at which $\Delta L/L_0 = 0$.
6*	1107	Maeland, A.J.	1964	X	441-551	$VH_{0.75}$	Similar to the above specimen; different composition; lattice parameter reported at 441 K as 3.1654 Å; this curve is here reported using the first given temperature 441 K as the reference temperature at which $\Delta L/L_0 = 0$.
7*	1108	Westlake, D.G. and Ockers, S.T.	1970	L	114-356		Specimen made by reacting metal (obtained from Semi-Elements, Inc.; composition: 0.0025 Si, 0.002 Ti, 0.0005 Fe, 0.0003 N, 0.0001 each Cr, Mo, O) with hydrogen at pressures > 400 Torr and at 1073 K for 1 hr; then cooled to 573 K at 100 °C/hr and held overnight; temperature reduced to 473 K at 10 10 °C/hr and held overnight; cooled to 453 K and held for 7 hr; finally, sample was furnace-cooled; hydrogen content determined by weight gain.

* No figure given.

DATA TABLE 302. THERMAL LINEAR EXPANSION OF VANADIUM HYDRIDE VH

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
296	0.030
339	0.474
363	0.764
386	0.909
406	0.962
467	1.054
518	1.084
582	1.166
CURVE 2*,†	
373	0.000
379	0.144
401	0.517
418	0.929
433	1.116
442	1.185
451	1.214
460	1.234
466	1.267
513	1.322
597	1.388
CURVE 3*,†	
470	0.000
485	0.110
499	0.126
523	0.177
582	0.242
596	0.287
CURVE 4*,†	
477	0.000
498	0.026
513	0.000
542	0.090
575	0.090
585	0.128
CURVE 5*,†	
459	0.000
463	-0.083
535	0.035
582	0.054
588	0.054
CURVE 6*,†	
441	0.000
474	-0.022
551	0.199
CURVE 7*	
114	-0.201
121	-0.196
126	-0.192
134	-0.188
140	-0.183
144	-0.179
151	-0.174
155	-0.170
160	-0.166
164	-0.162
170	-0.157
174	-0.153
178	-0.149
182	-0.144
186	-0.140
190	-0.136
194	-0.131
203	-0.122
207	-0.117
210	-0.114
213	-0.108
217	-0.105
221	-0.101
225	-0.096
228	-0.091
231	-0.087
235	-0.084
238	-0.079
241	-0.075
245	-0.070
CURVE 7 (cont.)*	
248	-0.066
252	-0.061
254	-0.057
258	-0.053
261	-0.049
264	-0.044
267	-0.040
270	-0.036
273	-0.032
277	-0.029
279	-0.022
281	-0.018
284	-0.013
287	-0.009
290	-0.005
293	0.000
297	0.004
300	0.008
302	0.013
304	0.016
308	0.021
310	0.025
313	0.030
316	0.034
318	0.038
321	0.042
323	0.047
326	0.051
328	0.055
331	0.060
334	0.066
336	0.069
338	0.074
341	0.078
343	0.081
346	0.086
349	0.090
352	0.095
354	0.098
356	0.103

* No figure given.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

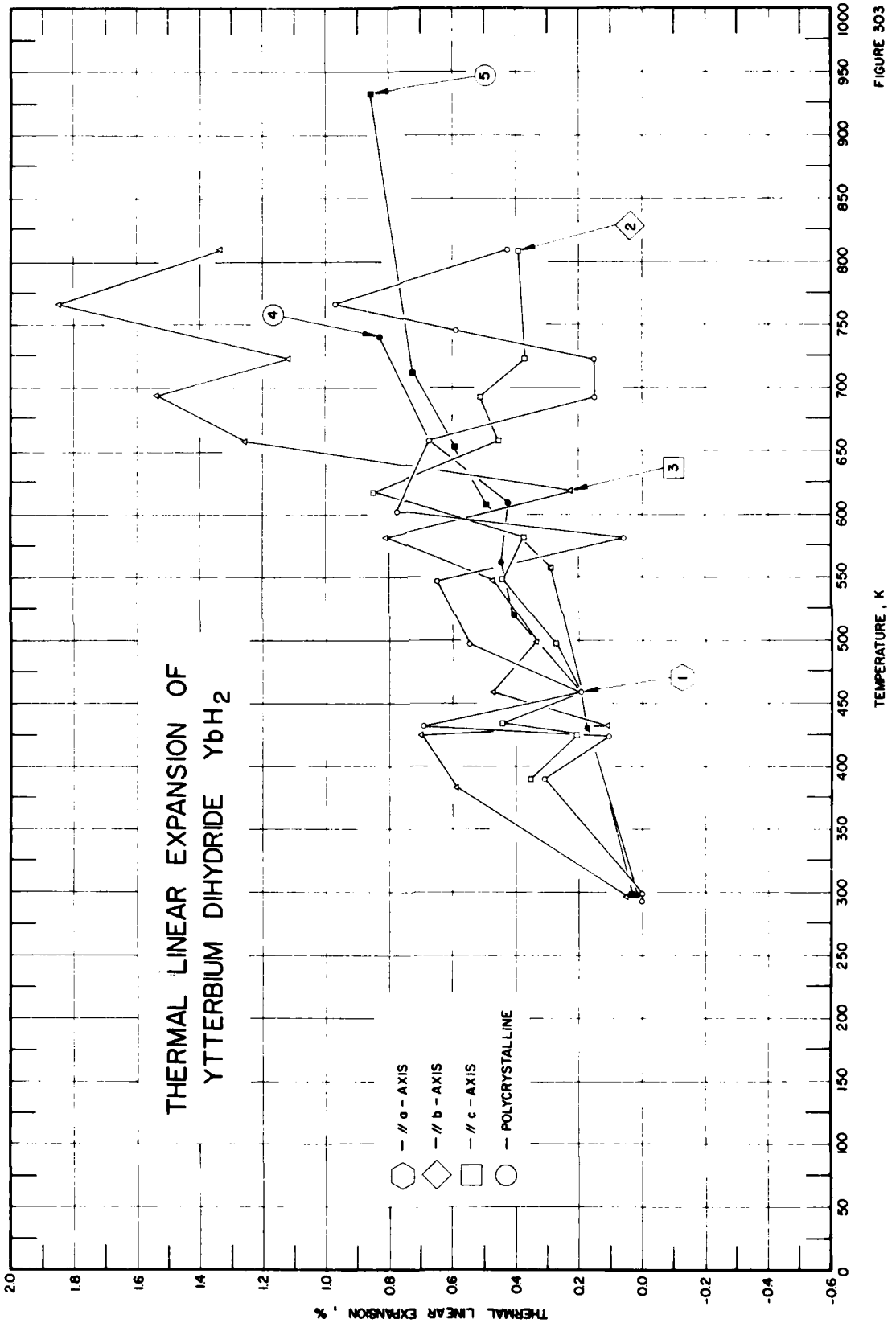

THERMAL LINEAR EXPANSION OF
YTTERBIUM DIHYDRIDE YbH2
// a - AXIS
// b - AXIS
// c - AXIS
POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1
2
3
4
5

FIGURE 303

SPECIFICATION TABLE 303. THERMAL LINEAR EXPANSION OF YTTERBIUM DIHYDRIDE YbH_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1109	Messer, C.E. and Gainovkos, D.C.	1968	X	293-810	$YbH_{1.90}$	Orthorhombic structure; prepared by degassing metal at 673 K for 2 hr prior to weighing and hydriding in argon filled glove box; hydriding metal with hydrogen occurred at an elevated temperature; sample placed on stainless steel block in a shallow, square recess; stainless steel block placed on ceramic block; inside chamber at 1.5 atm; sample heated to desired temperature in 30 min and held constant during measurements for 2 hr; expansion measured along a-axis; lattice parameter reported at 299 K as 6.802 Å; 6.802 Å at 293 K determined by graphical extrapolation.
2	1109	Messer, C.E. and Gainovkos, D.C.	1968	X	293-808		Same as the above; expansion measured along b-axis; lattice parameter reported at 299 K as 5.892 Å; 5.892 Å at 293 K determined by graphical extrapolation.
3	1109	Messer, C.E. and Gainovkos, D.C.	1968	X	293-810		Same as the above; expansion measured along c-axis; lattice parameter reported at 297 K as 3.573 Å; 3.571 Å at 293 K determined by graphical extrapolation.
4	1109	Messer, C.E. and Gainovkos, D.C.	1968	X	293-740		Similar to the above; cubic structure; β phase; lattice parameter reported at 298 K as 5.191 Å; 5.190 Å at 293 K determined by graphical extrapolation.
5	1109	Messer, C.E. and Gainovkos, D.C.	1968	X	293-934		Similar to the above; cubic structure; β' phase; lattice parameter reported at 299 K as 5.2521 Å; 5.250 Å at 293 K determined by graphical extrapolation.

DATA TABLE 303. THERMAL LINEAR EXPANSION OF YTTERBIUM DIHYDRIDE YbH_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3		CURVE 4		CURVE 5 (cont.)	
293	0.000	293	0.000	293	0.000	293	0.000	653	0.550
299	0.000	299	0.000	297	0.056	298	0.019	711	0.724
390	0.309	390	0.356	383	0.588	430	0.173	934	0.857
424	0.103	425	0.204	425	0.700	458	0.193		
432	0.691	434	0.441	432	0.112	520	0.405		
459	0.191	459	0.187	458	0.476	561	0.443		
496	0.544	497	0.222	497	0.336	609	0.424		
547	0.647	548	0.441	547	0.476	657	0.674		
581	0.059	581	0.373	582	0.812	740	0.829		
602	0.779	616	0.849	618	0.224				
658	0.676	658	0.458	658	1.260	CURVE 5			
691	0.147	692	0.509	694	1.540				
723	0.147	723	0.373	723	1.120	293	0.000		
745	0.588	808	0.390	766	1.[illegible]	299	0.038		
766	0.970			810	1.[illegible]	559	0.286		
810	0.426					608	0.495		

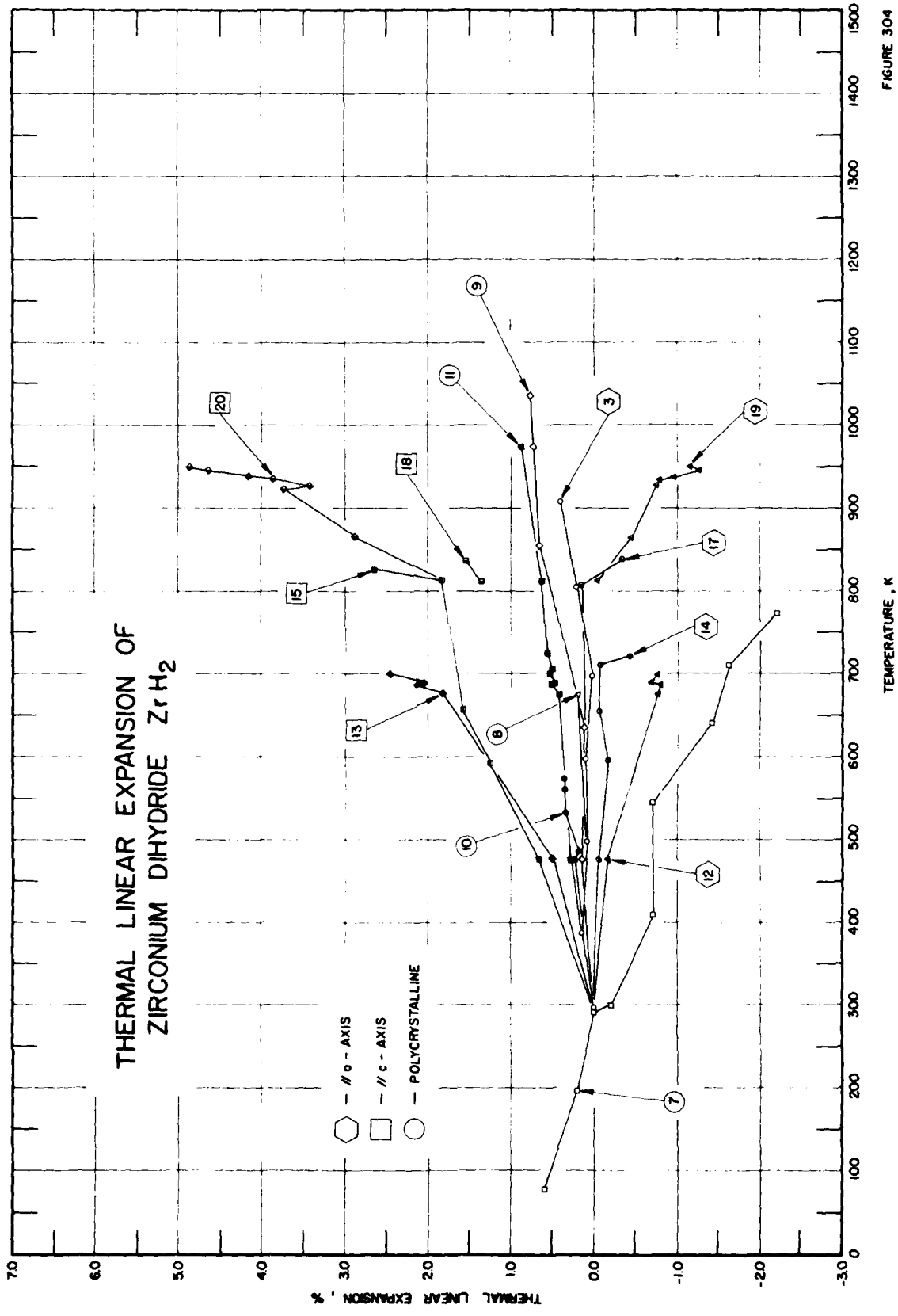

THERMAL LINEAR EXPANSION OF
ZIRCONIUM DIHYDRIDE ZrH_2
// a - AXIS
// c - AXIS
POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 304

SPECIFICATION TABLE 304. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIHYDRIDE ZrH_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	1102	Coon, E.J. and Malgiolio, J.	1958	X	485-899		Specimen prepared from epsilon phase; nuclear grade crystal bar Zr [impurities < 0.01] from Westinghouse Electric Corporation; sampled etched in solution of 5% HF, 45% HNO_3, 50% H_2O in polyethylene were until surface lustrous; washed in distilled water isopropyl alcohol and anhydrous ether; quickly weighed in air; re-etched and washed as above; placed in Vycor tube containing argon gas on a stainless steel boat; hydriding format by heating specimen until first sign of H pickup occurred; temperature increased 100 K and held constant until absorption was completed; expansion measured along a-axis at 1 atmosphere of H; lattice parameter reported at 485 K as 4.973 Å; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
2*	1102	Coon, E.J. and Malgiolio, J.	1958	X	485-899		Same as the above; expansion measured along c-axis; lattice parameter reported at 485 K as 4.473 K; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
3	1102	Coon, E.J. and Malgiolio, J.	1958	X	293-908		Same as the above; expansion measured along a-axis and at H gas pressure of 24-26 kg/cm^2; lattice parameter reported at 293 K as 4.976 Å.
4*	1102	Coon, E.J. and Malgiolio, J.	1958	X	293-908		Same as the above; expansion measured along c-axis and at H gas pressure of 24-26 kg/cm^2; lattice parameter reported at 293 K as
5*	1102	Coon, E.J. and Malgiolio, J.	1958	X	375-1038		Same as the above; expansion measured along a-axis and at 38-40 kg cm^2; lattice parameter reported at 375 K as 4.967 Å; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
6*	1102	Coon, E.J. and Malgiolio, J.	1958	X	375-1038		Same as the above; expansion measured along c-axis and at 38-40 kg cm^2; lattice parameter reported at 375 K as 4.465 Å; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
7	1103	Yakel, H. L.	1957	X	79-777	$ZrH_{1.92}$	Prepared by cold-rolling sections of 5 mil Zr foil [from arc melted crystal bar Zr]; hydriding done by heating Zr in vacuum to 1273 K; H gas entered at 1273 K; system cooled to 673 K and held constant for several hours.
8	1104, 1105	Barontseva, I.G. and Antonova, M.M.	1969	L	293, 673		97.76 Zr and 2.14 H; cylindrical specimen, 8 mm diameter x 15 mm long; prepared by heating Zr briquettes to 1023 K for 30 min in H gas; gas flow rate was 300 cm/min; reported density; 400-4.35 g cm^3, porosity 21-27%.
9	1110	Moore, K. E. and Young, W.A.	1968	X	297-1033		90.11 Zr, 9.83 U, 0.04 O, and 0.004 N; prepared by hydriding SNAP reactor fuel alloy [impurities < 0.28%, produced by triple arc melting and double extrusion of Zr-U metal]; sample crushed, powdered to -325, +400 screen mesh size in argon glove box; placed in 0.5 mm quartz capillary and sealed at 10^{-4} Torr; data taken after waiting 30 min at test temperature; Nielson-Riley function used to correct systematic error; H/Zr atom ratio 1.64; data reported for fcc phase; lattice parameter reported at 297 K as 4.7800 Å; 4.7798 Å at 293 K determined by graphical extrapolation.
10	1110	Moore, K. E. and Young, W.A.	1968	X	297-573		Similar to the above; H/Zr atom ratio 1.67, data reported for fcc phase; for fct phase, lattice parameter reported for a-axis as 4.896 Å and for c-axis, 4.576 Å at 298 K; lattice parameter for fcc phase reported at 297 K as 4.2803 Å; 4.7800 Å at 293 K determined by graphical extrapolation.

* Not shown in figure.

SPECIFICATION TABLE 304. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIHYDRIDE ZrH_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
11	1110	Moore, K. E. and Young, W. A.	1968	X	297-977		Similar to the above; H/Zr atom ratio 1.70; data reported for fcc phase; lattice parameter reported at 297 K as 4.7807 Å; 4.7804 Å at 293 K determined by graphical extrapolation.
12	1110	Moore, K. E. and Young, W. A.	1968	X	297-700		Similar to the above; H/Zr atom ratio 1.70; data reported for fct phase; expansion measured along a-axis; lattice parameter reported at 297 K as 4.894 Å; 4.8941 Å at 293 K determined by graphical extrapolation.
13	1110	Moore, K. E. and Young, W. A.	1968	X	297-700		Similar to the above; H/Zr atom ratio 1.70; data reported for fct phase; expansion measured along c-axis; lattice parameter reported at 297 K as 4.504 Å; 4.5834 Å at 293 K determined by graphical extrapolation.
14	1110	Moore, K. E. and Young, W. A.	1968	X	297-823		Similar to the above; H/Zr atom ratio 1.73; data reported for fct phase; expansion measured along a-axis; lattice parameter reported at 297 K as 4.8941 Å; 4.8941 Å at 293 K determined by graphical extrapolation.
15	1110	Moore, K. E. and Young, W. A.	1968	X	297-823		Simi'ar to the above; H/Zr atom ratio 1.73; data reported for fct phase; expansion measured along c-axis; lattice parameter reported at 297 K as 4.5807 Å; 4.5800 Å at 293 K determined by graphical extrapolation.
16*	1110	Moore, K. E. and Young, W. A.	1968	X	825-889		Similar to the above; H/Zr atom ratio 1.73; data reported for fcc phase; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$; lattice parameter reported at 825 K as 4.819 Å.
17	1110	Moore, K. E. and Young, W. A.	1968	X	291-839		Similar to the above; H/Zr atom ratio 1.76; data reported for fcc phase; expansion measured along a-axis; lattice parameter reported at 297 K as 4.92011 Å; 4.9200 Å at 293 K determined by graphical extrapolation.
18	1110	Moore, K. E. and Young, W. A.	1968	X	297-839		Similar to the above; H/Zr atom ratio 1.76; data reported for fcc phase; expansion measured along c-axis; lattice parameter reported at 297 K as 4.539 Å; 4.538 Å at 293 K determined by graphical extrapolation.
19	1110	Moore, K. E. and Young, W. A.	1968	X	297-950		Similar to the above; H/Zr atom ratio 1.81; data reported for fcc phase; expansion measured along a-axis; lattice parameter reported at 297 K as 4.9369 Å; 4.9369 Å at 293 K determined by graphical extrapolation.
20	1110	Moore, K. E. and Young, W. A.	1968	X	297-956		Similar to the above; H/Zr atom ratio 1.81; data reported for fcc phase; expansion measured along c-axis; lattice parameter reported at 297 K as 4.508 Å; 4.5073 Å at 293 K determined by graphical extrapolation.
21	1111	Kempter, C. P., Elliott, R. O., and Gschneidner, K. A., Jr.	1960	X	301-635	δ-$ZrH_{1.46}$	98.31 Zr, 1.59 H; fcc structure; prepared by hydriding Zr; crushed in He dry box to 325 screen mesh size; powder mixed with small amount of powdered Ag prior to sealing in evacuated silica tubes; lattice parameter reported at 301 K as 4.77887 Å; 4.778779 Å at 293 K determined by graphical extrapolation.
22	1111	Kempter, C. P., et al.	1960	X	635-297	δ-$ZrH_{1.46}$	Same as the above specimen; expansion measured with decreasing temperature; lattice parameter reported at 297 K as 4.77844 Å; 4.77839 Å at 293 K determined by graphical extrapolation.
23	1111	Kempter, C. P., et al.	1960	X	297-573	ϵ-$ZrH_{1.96}$	2.12 H; bcc structure; prepared by hydriding Zr; crushed in He filled dry box to 325 screen mesh size; lattice parameter measured at 297 K as 4.97565 Å; 4.9756 Å at 293 K determined by graphical extrapolation; expansion measured along a-axis.

* Not shown in figure.

SPECIFICATION TABLE 304. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIHYDRIDE ZrH_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
24	1111	Kempter, C.P., Elliott, R.O., and Gschneidner, K.A., Jr.	1960	X	297-573	ϵ-$ZrH_{1.96}$	Same as the above specimen; expansion measured along c-axis; lattice parameter reported at 297 K as 4.45095 Å; 4.45055 Å at 293 K determined by graphical extrapolation.
25	1112	Watroos, J.D.	1961	L	293-966	$ZrH_{1.7}$	Cylindrical; 0.510-0.630 cm diameter x 2.30-5.58 cm long; prepared by massively hydriding Zr (reactor grade, swaged from crystal bar stock); heating rate 3 C/min; expansion measured at 5×10^{-3} torr.

DATA TABLE 304. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIHYDRIDE ZrH_2

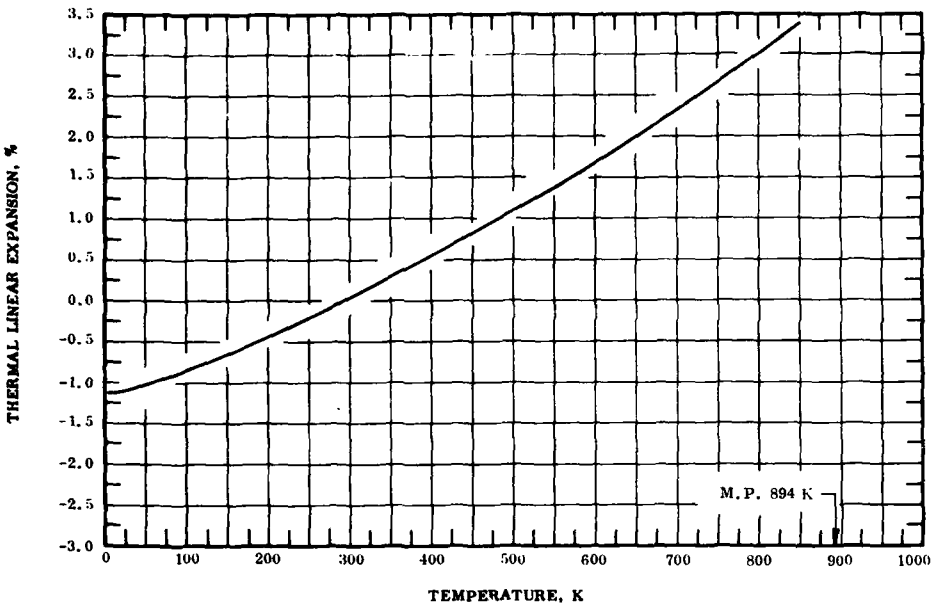
[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*,†	
485	0.000
683	-0.060
800	-0.241
899	-0.241
CURVE 2*,†	
485	0.000
683	0.671
800	1.364
899	2.124
CURVE 3	
293	0.000
386	-0.141
496	-0.080
599	-0.100
697	-0.121
805	-0.201
805	-0.221
908	-0.402
CURVE 4*	
293	0.000
386	0.292
496	0.540
599	0.899
697	1.192
805	1.844
805	2.001
908	2.945
CURVE 5*,†	
375	0.000
491	-0.020
593	-0.040
689	-0.040
806	-0.060
911	-0.181
913	-0.161
1038	-0.685
CURVE 6*,†	
375	0.000
491	0.314
593	0.627
689	1.053
806	1.815
911	2.240
913	2.285
1038	2.285
CURVE 7	
79	0.060
197	0.020
293	0.000
300	-0.020
411	-0.060
547	-0.060
641	-0.141
713	-0.161
777	-0.221
CURVE 8	
293	0.000
673	0.200
CURVE 9	
297	0.004
477	0.138
639	0.104
855	0.652
977	0.732
1033	0.786
CURVE 10	
297	0.006
477	0.202
483	0.177
533	0.328
561	0.334
573	0.378
CURVE 11	
297	0.006
477	0.286
673	0.420
689	0.535
689	0.493
700	0.537
708	0.535
755	0.587
812	0.625
977	0.889
CURVE 12	
297	-0.002
477	-0.165
673	-0.717
689	-0.778
689	-0.680
700	-0.758
CURVE 13	
297	0.013
477	0.536
673	1.802
689	2.151
689	2.042
700	2.478
CURVE 14	
297	0.000
477	-0.042
594	-0.190
655	-0.063
811	0.079
823	-0.410
CURVE 15	
297	0.015
277	0.698
594	1.244
655	1.091
811	1.834
823	2.685
CURVE 16*,†	
825	0.000
842	-0.166
889	0.000
CURVE 17	
297	0.002
811	0.197
839	-0.386
CURVE 18	
297	0.022
811	1.366
839	1.542
CURVE 19	
297	0.000
811	-0.014
866	-0.484
922	-0.781
927	-0.939
933	-0.775
939	-0.980
944	-1.217
950	-1.152
CURVE 20	
297	0.015
811	1.812
866	2.873
922	3.749
927	3.700
933	3.875
939	4.1732
944	4.652
950	4.896
CURVE 21	
301	0.001
383	0.021
488	0.031
574	0.069
635	0.105
CURVE 22	
635	0.113
524	0.051
439	0.037
297	0.001
CURVE 23	
297	0.000
368	0.003
479	-0.005
573	-0.085
CURVE 24	
297	0.008
378	0.168
469	0.496
573	0.899
CURVE 25	
293	0.000
325	0.014
350	0.030
375	0.044
400	0.062
425	0.082
450	0.100
475	0.123
500	0.147
525	0.169
550	0.195
575	0.222
600	0.249
625	0.279
650	0.310
675	0.337
700	0.373
725	0.407
750	0.443
775	0.477
800	0.514
825	0.549
850	0.585
875	0.625
900	0.665
CURVE 25 (cont.)	
925	0.708
950	0.751
966	0.780

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

FIGURE AND TABLE NO. 305R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF CESIUM IODIDE CsI



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
2	-1.140	0.013
5	-1.140	0.22
10	-1.139	2.5
15	-1.137	7.8
20	-1.131	14.0
25	-1.123	20.0
50	-1.053	36.0
75	-0.962	39.1
100	-0.863	41.5
150	-0.652	43.5
200	-0.432	44.8
250	-0.204	46.5
293	0.000	48.3
350	0.282	50.5
400	0.540	52.7
500	1.090	57.4
600	1.686	62.0
700	2.331	67.0
800	3.026	72.0
850	3.393	74.7

REMARKS

The recommended values are based on curves 1 and 3 (2-573 K) and curve 5 (298-668 K) which are consistent with one another and follow the general trend for other iodides. These values are considered accurate to within ±3% and are represented approximately by the following equation:

$$\Delta L/L_0 = -1.253 + 3.760 \times 10^{-3}\, T + 1.636 \times 10^{-6}\, T^2 + 4.384 \times 10^{-10}\, T^3 \qquad (150\text{-}850\ K)$$

The tabulated values for the coefficient of thermal expansion at temperatures below 700 K are based on the experimental data and those above 700 K are extrapolated.

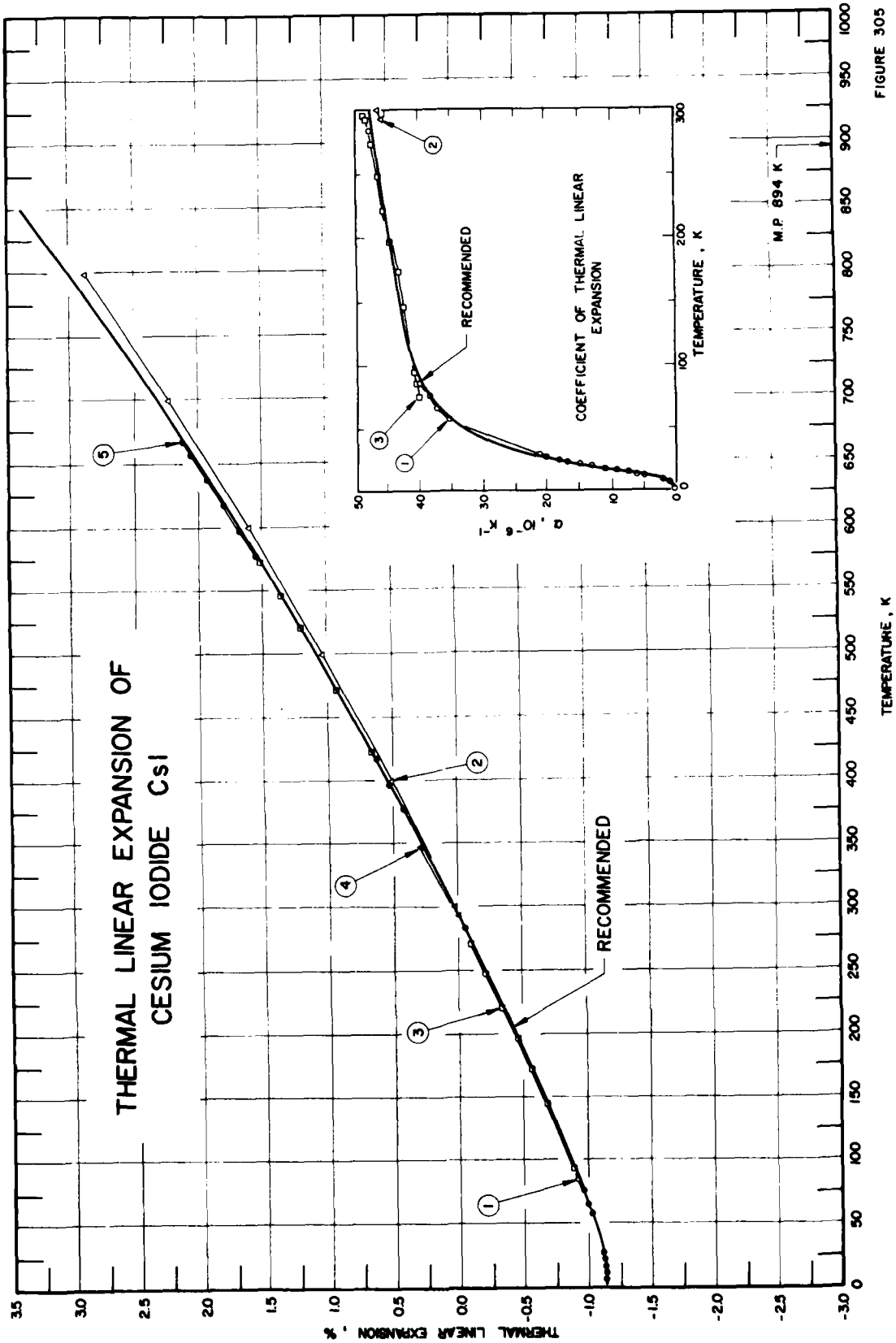

THERMAL LINEAR EXPANSION OF
CESIUM IODIDE CsI
RECOMMENDED
M.P 894 K
TEMPERATURE, K
THERMAL LINEAR EXPANSION, %
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
TEMPERATURE, K
α, 10⁻⁶ K⁻¹

FIGURE 305

SPECIFICATION TABLE 305. THERMAL LINEAR EXPANSION OF CESIUM IODIDE CsI

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	623	White, G.K. and Collins, J.G.	1973	E	2-283		Dimensions: 20 mm diameter, 50.8 mm long; specimen obtained from Isomet Corp. of New Jersey; this curve is here reported utilizing other coefficients of thermal linear expansion from 63 K to 283 K for integration purposes.
2	625	Srivastava, K.K. and Merchant, H.D.	1972	X	293-900		No details given.
3	626	Rapp, J.E. and Merchant, H.D.	1972	L	74-573		Orientation of crystal < 1, 1, 1>; specimen was 5 x 5 x 25 mm; smoothed data.
4	632	Bridgman, P.W.	1932		303, 348		Dimensions: cylindrical, 0.953 cm diameter x 0.952-1.27 cm long; specimen pressed; used lever piezometer method used to determine expansion.
5	783	Panter, C.H.	1973	I	298-668		Dimensions: hollow cylinder, 25 mm O.D., 13 mm I.D. x 7.52 mm long; expansion measured in inverted stainless steel dewar glass filled with He exchange gas at 3 mm Hg pressure.

DATA TABLE 305. THERMAL LINEAR EXPANSION OF CESIUM IODIDE CsI

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 1 (cont.)‡		CURVE 3 (cont.)‡		CURVE 4		CURVE 5 (cont.)‡	
2.332	-1.137	9.032	-1.136	85.000	-0.922	94	-0.888	303	0.054*	558	1.445*
2.881	-1.137	9.744	-1.136	283.000	-0.048	145	-0.675	348	0.302	578	1.567
3.279	-1.137	10.605	-1.136			172	-0.558			598	1.691
3.575	-1.137	11.605	-1.136	CURVE 2‡		196	-0.452	CURVE 5‡		618	1.817
3.854	-1.137	12.682	-1.135			220	-0.343			638	1.945
4.007	-1.137	13.829	-1.134	293	0.000	248	-0.214	298	0.025*	658	2.075
4.199	-1.137	15.030	-1.134	300	0.032	272	-0.101	318	0.123*	668	2.140
4.440	-1.137	16.339	-1.132	400	0.519	293	0.000*	338	0.224*		
4.705	-1.137	17.825	-1.131	500	1.049	296	0.015*	358	0.326*		
4.875	-1.137	19.386	-1.129	600	1.621	324	0.153*	378	0.430		
5.206	-1.137	20.950	-1.127	700	2.236	373	0.402*	398	0.536		
5.581	-1.137	22.611	-1.124	800	2.892	423	0.667	418	0.643		
5.917	-1.137	24.114	-1.121	900	3.586*	472	0.937	438	0.752*		
6.292	-1.136	25.623	-1.118			521	1.219	458	0.863*		
6.709	-1.136	27.149	-1.115	CURVE 3‡		546	1.366	478	0.976*		
7.176	-1.136	57.500	-1.028			573	1.529	498	1.090*		
7.722	-1.136	65.000	-1.000	74	-0.970*			518	1.207*		
8.354	-1.136	75.000	-0.962	84	-0.929*			538	1.325*		

DATA TABLE 305. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CESIUM IODIDE CsI

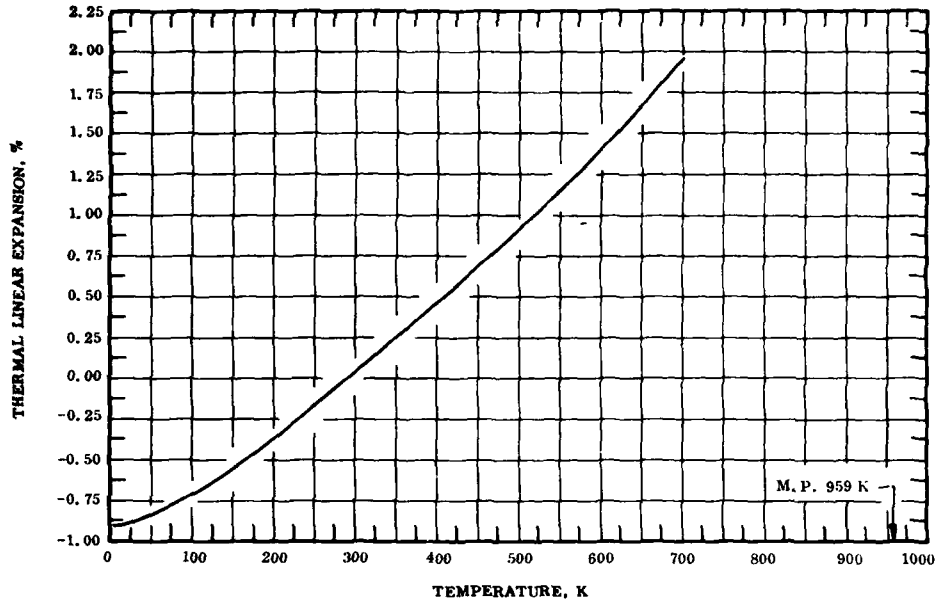
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α	T	α	T	α
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 1 (cont.)‡		CURVE 3 (cont.)‡		CURVE 5*,‡		CURVE 5 (cont.)*,‡	
2.332	0.0201	9.032	1.7260*	85.000	40.15	94	41.0	298	49.00	658	65.50
2.881	0.0375*	9.744	2.2230	283.000	48.00	145	42.7	318	49.75	668	66.00
3.279	0.0577*	10.605	2.9390*			172	43.6	338	50.75		
3.575	0.0725*	11.605	3.8390	CURVE 2‡		196	44.9	358	51.50		
3.854	0.0930*	12.682	5.0700			220	45.7	378	52.35		
4.007	0.1070*	13.829	6.3000	293	46.0	248	46.6	398	53.25		
4.199	0.1230*	15.030	7.8500	300	46.6	272	47.6	418	54.15		
4.440	0.1450*	16.339	9.4400	400	50.8*	293	48.8	438	55.00		
4.705	0.1780*	17.825	11.34	500	55.2*	296	49.0	458	55.90		
4.875	0.1980*	19.386	13.36	600	59.2*	324	49 8*	478	56.85		
5.206	0.2480*	20.950	15.24	700	63.7*	373	52.0*	498	57.75		
5.581	0.3150*	22.611	17.27	800	67.6*	423	53.9*	518	58.65		
5.917	0.3870*	24.114	18.63	900	71.1*	472	56.4*	538	59.40		
6.292	0.4820*	25.623	20.45			521	58.4*	558	60.50		
6.709	0.6110*	27.149	21.76	CURVE 3‡		546	59.7*	578	61.50		
7.176	0.7740*	57.500	35.81			573	60.9*	598	62.40		
7.722	1.0100	65.000	37.58	74	40.2			618	63.50		
8.354	1.3290*	75.00	38.93	84	40.6			638	64.50		

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 306R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF POTASSIUM IODIDE KI



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
4	-0.895	0.02
5	-0.895	0.04
10	-0.895	0.54
15	-0.894	2.1
20	-0.893	4.7
25	-0.890	7.6
50	-0.853	21.5
75	-0.790	28.5
100	-0.715	31.8
150	-0.546	35.5
200	-0.362	37.5
250	-0.170	39.0
293	0.000	40.2
350	0.235	42.0
400	0.447	43.0
500	0.905	48.0
600	1.410	53.2
700	1.971	59.0

REMARKS

The recommended values are based on the data for high purity samples. These values are considered accurate to within ±5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -1.083 + 3.511 \times 10^{-3}\, T + 2.180 \times 10^{-7}\, T^2 + 1.428 \times 10^{-8}\, T^3 \qquad (150\text{–}700\ K)$$

The tabulated values for the coefficient of thermal expansion are based on the selected experimental data and are considered accurate to about ±10%.

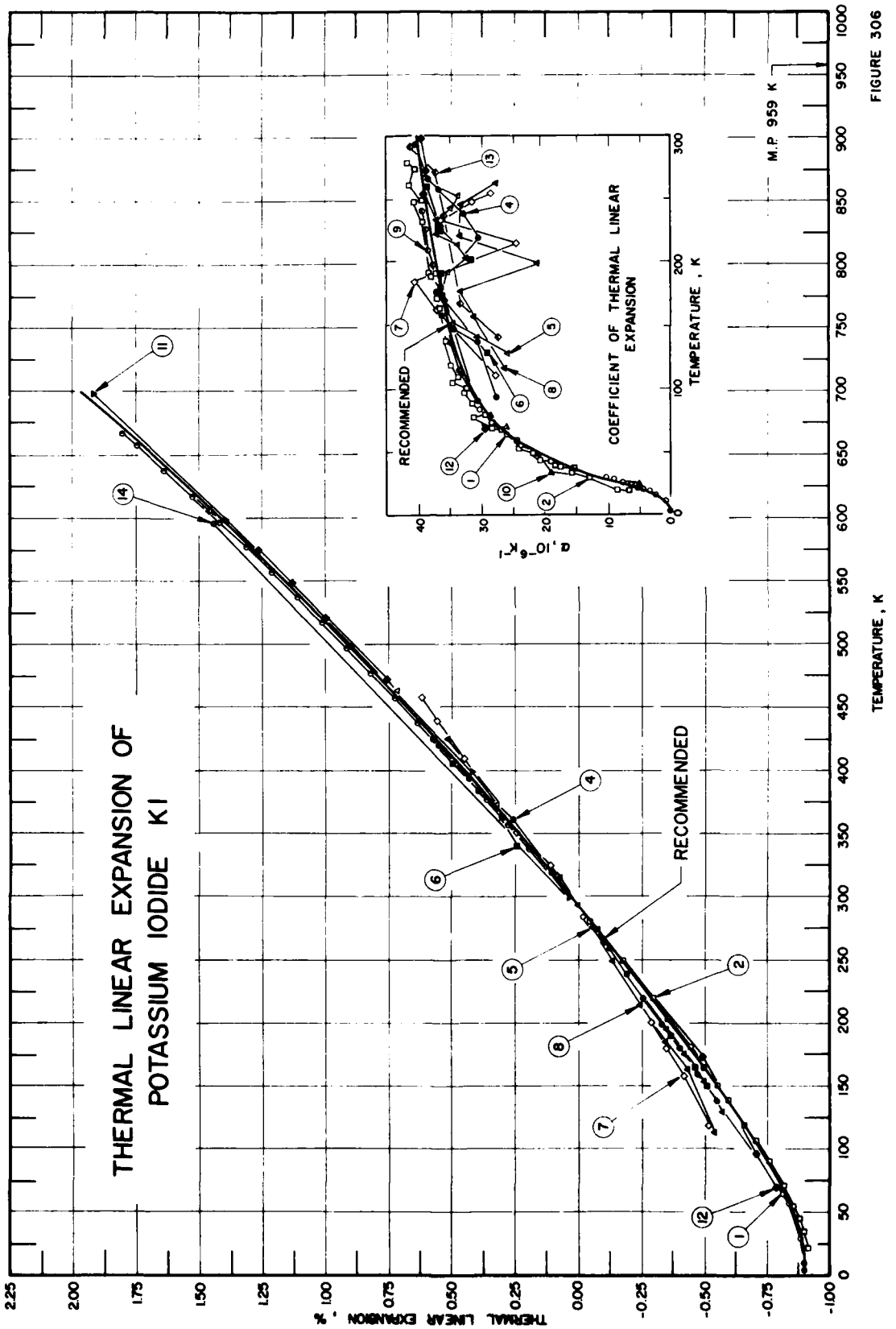

THERMAL LINEAR EXPANSION OF
POTASSIUM IODIDE KI
RECOMMENDED
M.P. 959 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
α , 10⁻⁶K⁻¹
TEMPERATURE , K

FIGURE 306

SPECIFICATION TABLE 306. THERMAL LINEAR EXPANSION OF POTASSIUM IODIDE KI

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	479	White, G.K.	1965	C	4-283		Cylindrical; 2 cm diameter, 5 cm long; optical quality from Harshaw Chemical Company; this curve is here reported utilizing other coefficients of thermal linear expansion for integration.
2	480	Yates, B. and Panter, C.H.	1962	I	22-281		Single crystal 99.997+ pure from Harshaw Chemicals Ltd. of Cleveland; expansion observed with cadmium green light (5085.8 Å).
3	483	Connell, L.F. and Martin, H.C. Martin, H.C., Jr.	1951	X	293-463		Specimen prepared from 99.95+ pure C. P. Baker's Analyzed K1; expansion observed using Fe Kα x-radiation.
4	801	Srinivasan, R.	1955	I	138.1-420.9	Heating 1	One set of three spacers of specimen of potassium iodide grown by melt in laboratory by Dr. Vedan and Mr. Gopalakrishnan; the substance of crystal was an extra pure sample supplied by Merck and Co.; the crystal was grown in a porcelain crucible and was annealed for two days; the crystal was clear and transparent.
5	801	Srinivasan, R.	1955	I	130.2-277.2	Heating 2	Similar to the above specimen except Heating 2 (2 run).
6	801	Srinivasan, R.	1955	I	131.1-427.1		Set of three spacers was prepared from a specimen of pure potassium iodide supplied by Harshaw Chemical Co.
7	802	Viswamitra, M.A. and Ramaseshan, S.	1962	X	113-427	No. 1	Specimen cut from large single crystal grown by Kryopoulos technique using Merck's Analytical Reagent.
8	802	Viswamitra, M.A. and Ramaseshan, S.	1962	X	118-458	No. 2	Similar to the above specimen, cut from same crystal.
9*	803	Cooper, R.F. and Yates, B.	1970	I	81.6-263.5		Specimen form of hollow cylinder of single crystal, grown by New Metals and Chemicals Ltd., using starting material containing impurities below 0.03.
10*	757	Awad, F.C. and Gugan, D.	1971	E	10-80		Optical purity sample, obtained from Harshaw Chemicals Ltd., single crystal samples, three runs made on sample, these results were smoothed, and rounded values of thermal expansion coefficient given; error limits of ±2% on thermal expansion coefficient.
11	625	Srivastava, K.K. and Merchant, H.D.	1972	X	293-700		No details given.
12	626	Rapp, J.E. and Merchant, H.D.	1972	L	70-577		Crystal orientation was (1,0,0); dimensions were 5 x 5 x 33 mm; smoothed data.
13*	663	Von Trost, K.F.	1963		142-719		No details given.
14	664	Whittemore, D.O.	1962	L	293,593		Dimension: cylinder, 1.27 cm diameter x 2.54 cm long; specimen formed by pressing reagent grade chemicals into a steel mold at 10,000 psi; original length measured by micrometer to 2.54 μm; measurement made by placing two cylinders end to end.
15	804	Panter, C.H.	1973	I	298-668		Dimension: 8.68 mm long pyramids (three of these pyramids made one sample); expansion measured in inverted stainless steel dewar vessel filled with He exchange gas at 3 mm Hg.

* Not shown in figure.

DATA TABLE 306. THERMAL LINEAR EXPANSION OF POTASSIUM IODIDE KI

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
4	-0.892
5	-0.892
6	-0.892
7	-0.892
8	-0.892
10	-0.892
12	-0.892
14	-0.892
16	-0.891
18	-0.891
20	-0.890
22	-0.889
24	-0.887
26	-0.886
28	-0.884
30	-0.882
57.5	-0.835
65	-0.817
75	-0.789
85	-0.760
283	-0.040
CURVE 2‡	
22	-0.910
22	-0.910*
25	-0.907*
26	-0.907*
29	-0.904*
31	-0.902*
31	-0.902*
35	-0.896
36	-0.895*
39	-0.890*
40	-0.888*
41	-0.886*
43	-0.883*
44	-0.881*
45	-0.879
47	-0.875*
48	-0.873*
49	-0.871*
50	-0.869*
51	-0.867*
53	-0.862*
54	-0.860*
56	-0.855
CURVE 2 (cont.)‡	
57	-0.853*
60	-0.846*
63	-0.838*
65	-0.832*
67	-0.827*
71	-0.816*
71	-0.816
74	-0.807*
77	-0.798*
78	-0.795*
81	-0.786*
89	-0.763*
90	-0.760
93	-0.750*
99	-0.731*
102	-0.721*
107	-0.704
111	-0.691*
116	-0.674*
119	-0.663
126	-0.638*
139	-0.592
151	-0.550
153	-0.543*
162	-0.510*
165	-0.499
173	-0.470*
181	-0.440
188	-0.414*
190	-0.407
192	-0.399*
203	-0.358*
203	-0.358
216	-0.309*
220	-0.293
227	-0.266*
233	-0.243*
238	-0.223*
249	-0.179*
250	-0.175
263	-0.122*
263	-0.122*
275	-0.074
281	-0.049*
281	-0.049
CURVE 3	
293	0.000
373	0.325
463	0.716
CURVE 4‡	
138.1	-0.548
149.2	-0.512*
160.0	-0.474
170.7	-0.435*
179.9	-0.401
188.9	-0.368*
200.0	-0.329
209.7	-0.297*
221.2	-0.262
231.0	-0.229*
240.9	-0.194
250.7	-0.162*
260.2	-0.128
269.1	-0.095*
296.2	0.012
319.6	0.108
336.5	0.180*
362.1	0.291
378.6	0.364
394.6	0.436
406.9	0.492*
420.9	0.558
CURVE 5‡	
130.2	-0.573
142.5	-0.538*
154.2	-0.500
164.2	-0.464*
175.2	-0.423
185.1	-0.386*
194.9	-0.351
205.1	-0.316
215.2	-0.283
224.8	-0.249
235.3	-0.210
245.3	-0.174
255.0	-0.140
277.2	-0.059
CURVE 6‡	
131.1	-0.579
151.9	-0.516*
166.5	-0.467
176.8	-0.430*
184.9	-0.401*
192.9	-0.371
204.0	-0.333*
216.1	-0.294*
226.4	-0.258*
241.1	-0.205
251.6	-0.166*
261.0	-0.130
275.3	-0.073*
320.0	0.110*
342.4	0.205
364.1	0.300
385.5	0.395
406.1	0.489
427.1	0.588
CURVE 7‡	
113	-0.598
164	-0.433
186	-0.347
216	-0.249
235	-0.190*
250	-0.139
254	-0.126*
257	-0.118*
316	0.074
427	0.533
CURVE 8‡	
118	-0.532
158	-0.417
179	-0.348
201	-0.288
223	-0.228*
247	-0.148*
265	-0.093*
325	0.105*
351	0.206
359	0.238*
382	0.333*
CURVE 8 (cont.)‡	
394	0.383*
411	0.455
439	0.580
458	0.668
CURVE 9*,‡	
81.6	-0.776
90.5	-0.749
99.0	-0.723
108.1	-0.694
108.9	-0.691
117.2	-0.664
118.0	-0.661
124.4	-0.639
131.8	-0.614
139.3	-0.588
147.4	-0.559
156.6	-0.527
157.4	-0.524
166.2	-0.492
174.3	-0.462
175.7	-0.457
176.7	-0.453
180.7	-0.438
192.5	-0.394
195.9	-0.381
199.9	-0.366
204.8	-0.348
206.5	-0.341
207.2	-0.339
211.8	-0.321
216.8	-0.302
218.3	-0.296
223.3	-0.277
223.8	-0.275
228.1	-0.258
228.8	-0.255
230.0	-0.251
235.7	-0.229
236.6	-0.225
242.3	-0.203
249.0	-0.176
250.4	-0.170
263.5	-0.118
CURVE 10*,†,‡	
10	0.000000
12	0.000105
14	0.000297
16	0.000624
18	0.00113
20	0.00185
22	0.00279
24	0.00397
26	0.00543
28	0.00716
30	0.00918
35	0.0153
40	0.0230
45	0.0321
50	0.0423
60	0.0652
65	0.0776
70	0.0907
75	0.104
80	0.118
CURVE 11‡	
293	0.000*
300	0.028
400	0.444
500	0.901
600	1.395
700	1.924
CURVE 12‡	
70	-0.791
81	-0.758*
97	-0.709
112	-0.661*
121	-0.631*
147	-0.544*
174	-0.449
184	-0.412*
195	-0.372*
223	-0.269*
247	-0.179*
257	-0.141*
274	-0.074*
293	0.000*

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 306. THERMAL LINEAR EXPANSION OF POTASSIUM IODIDE KI (continued)

T	$\Delta L/L_0$
CURVE 12 (cont.)‡	
300	0.028*
322	0.116*
372	0.321*
421	0.530*
473	0.762
522	0.994
549	1.128
577	1.273
CURVE 13*,‡	
142	-0.503
169	-0.421
173	-0.408
185	-0.370
193	-0.346
223	-0.256
230	-0.233
239	-0.201
249	-0.166
268	-0.098
272	-0.082
293	0.000
330	0.157
347	0.232
370	0.334
498	0.927
563	1.245
607	1.466
719	2.067
CURVE 14	
293	0.00*
593	1.44
CURVE 15‡	
298	0.021*
318	0.104*
338	0.189
358	0.275
378	0.362
398	0.451*
418	0.541*
438	0.632
458	0.725
478	0.819
CURVE 15 (cont.)‡	
498	0.914
518	1.012
538	1.110
558	1.211
578	1.314
598	1.419
618	1.526
638	1.636
658	1.747
668	1.804

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 306. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POTASSIUM IODIDE KI

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
4	0.018
5	0.036*
6	0.066*
7	0.12*
8	0.21*
10	0.53*
12	1.00
14	1.80*
16	2.6
18	3.5
20	4.5
22	5.7
24	6.8
26	8.0
28	9.1
30	10.3
57.5	23.9
65	26.0
75	28.4
85	30.2
283	40.0
CURVE 2‡	
22	6.8
22	8.5
25	8.2
26	8.6*
29	9.3*
31	11.5*
31	13.1
35	15.7
36	15.7*
39	15.4
40	17.7
41	18.5
43	18.1
44	19.0
45	20.9
47	20.3*
48	19.6
49	20.8
50	20.1*
51	22.0
53	22.6*
54	24.1
56	23.2*

T	α
CURVE 2 (cont.)‡	
57	23.6*
60	24.2
63	26.9
65	28.2
67	27.9*
71	27.6
71	28.5*
74	28.4*
77	30.4*
78	31.1
81	29.2
89	29.9*
90	31.4
93	31.3*
99	32.8
102	32.4
107	34.4
111	33.9
116	34.9*
119	34.9
126	35.5*
139	35.3
151	35.6*
153	36.2*
162	36.3*
165	36.6
173	37.0
181	36.5
188	37.6*
190	38.0
192	37.2
203	38.2
203	37.4*
216	38.1*
220	38.4*
227	39.2*
233	39.2
238	39.2*
249	40.8
250	39.6
263	41.4
263	40.8*
275	40.5
281	41.1*
281	41.9

T	α
CURVE 4‡	
138.1	30.6
149.2	34.2
160.0	36.3
170.7	37.1*
179.9	37.1
188.9	36.7*
200.0	33.9*
209.7	31.2*
221.2	30.4
231.0	36.5
240.9	33.6
250.7	32.9
260.2	36.7
269.1	38.4
296.2	40.5
319.6	41.9*
336.5	43.1
362.1	43.5
378.6	44.7
394.6	45.1
406.9	46.9
420.9	47.1
CURVE 5‡	
130.2	26.1
142.5	30.6
154.2	34.5
164.2	36.7*
175.2	37.5*
185.1	37.5
194.9	35.2
205.1	32.3
215.2	33.9
224.8	37.1
235.3	37.1
245.3	34.9
255.0	33.9
277.2	39.6
CURVE 6‡	
131.1	29.1
151.9	32.2
166.5	34.4*
176.8	36.5

T	α
CURVE 6 (cont.)‡	
184.9	37.2*
192.9	36.2*
204.0	31.9
216.1	32.9*
226.4	36.7
241.1	36.5*
251.6	37.7*
261.0	38.7
275.3	40.0*
320.0	42.0*
342.4	43.1
364.1	44.1
385.5	44.8
406.1	46.5
427.1	47.9
CURVE 7‡	
113	27.8
164	37.0
186	40.9
216	24.6
235	36.9
250	31.6
254	30.2*
257	28.5
316	36.5*
427	46.1*
CURVE 8‡	
118	26.3
158	31.3
179	33.5
201	21.2
223	33.5
247	33.2
265	27.8
325	38.3*
351	39.4*
359	40.4*
382	42.2*
394	41.8*
411	42.8*
439	45.9*
458	46.8*

T	α
CURVE 9‡	
81.6	28.74*
90.5	30.52
99.0	31.48*
108.1	32.77*
108.9	32.96*
117.2	33.55
118.0	33.65*
124.4	34.19*
131.8	34.37*
139.3	34.97
147.4	35.37*
156.6	35.90
157.4	36.22*
166.2	36.51*
174.3	36.97*
175.7	37.26*
176.7	36.88*
180.7	37.09*
192.5	37.61*
195.9	37.69*
199.9	37.91
204.8	38.09*
206.5	38.14*
207.2	38.54*
211.8	38.02
216.8	38.39*
218.3	38.34*
223.3	38.98*
223.8	38.88*
228.1	38.94
228.8	38.94*
230.0	38.68*
235.7	39.06*
236.6	39.02*
242.3	39.64
249.0	39.68*
250.4	39.66*
263.5	39.99*
CURVE 10‡	
10	0.35
12	0.70*
14	1.22*
16	2.05*
18	3.02*

T	α
CURVE 10 (cont.)‡	
20	4.20*
22	5.20
24	6.58*
26	8.01*
28	9.33*
30	10.84*
35	14.00
40	16.79*
45	19.40*
50	21.51
60	24.21*
65	25.54*
70	26.73
75	27.73*
80	28.82
CURVE 11*,‡	
293	39.0
300	39.7
400	43.6
500	47.7
600	51.2
700	54.5
CURVE 12‡	
70	29.2
81	30.3*
97	31.4*
112	32.3*
121	32.9*
147	34.2*
174	36.2
184	37.3*
195	36.3*
223	37.1*
247	37.9*
257	39.2
274	38.8
293	39.4*
300	39.7
322	40.3*
372	41.9*
421	43.4*
473	45.8*

* Not shown in figure.

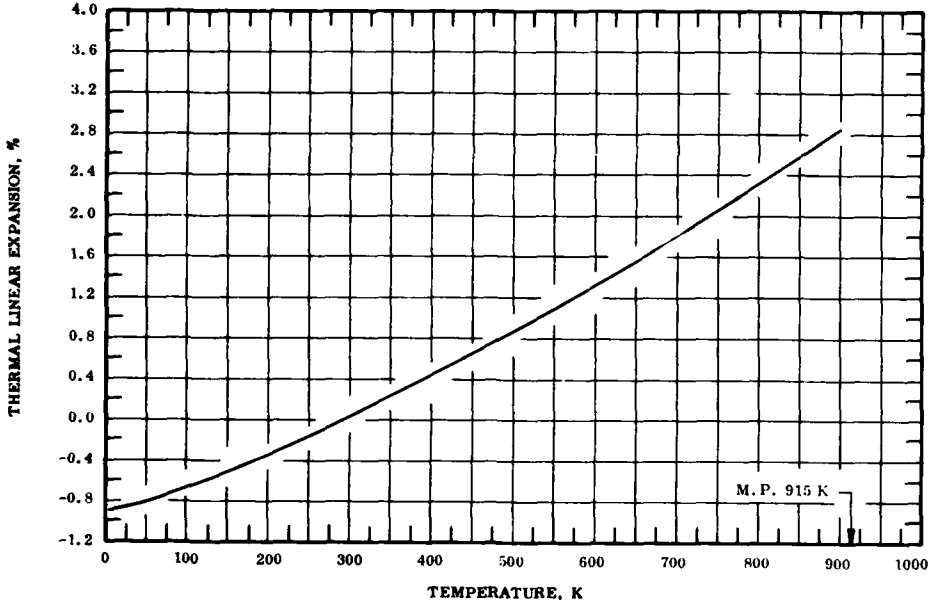
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 306. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POTASSIUM IODIDE KI (continued)

T	α
CURVE 12 (cont.)‡	
522	48.7*
549	50.5*
577	52.8*
CURVE 13*,‡	
142	27.1
169	33.3
173	32.9
185	30.3
193	29.7
223	30.3
230	35.4
239	36.0
249	33.7
268	38.2
272	37.4
293	41.1
330	43.8
347	44.3
370	44.6
498	48.1
563	49.6
607	51.0
719	56.2
CURVE 15*	
298	41.15
318	42.00
338	42.65
358	43.35
378	44.00
398	44.65
418	45.35
438	46.00
458	46.65
478	47.45
498	48.20
518	49.07
538	49.65
558	50.96
578	52.00
598	53.10
618	54.15
638	55.25
658	56.35
668	57.00

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 307R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF RUBIDIUM IODIDE RbI



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
2	-0.896	-0.003
3	-0.896	-0.006
4	-0.896	-0.015
5	-0.896	-0.032
6	-0.896	-0.042
7	-0.896	-0.035
8	-0.896	0.02
10	-0.896	0.30
15	-0.896	2.4
20	-0.894	6.0
25	-0.890	10.1
50	-0.844	24.0
75	-0.777	30.0
100	-0.699	32.3
150	-0.531	34.8
200	-0.352	36.5
250	-0.166	38.0
293	0.000	39.1
350	0.227	40.5
400	0.432	41.8
500	0.861	44.5
600	1.321	47.3
700	1.809	50.2
800	2.323	53.2
900	2.871	56.2

REMARKS

The recommended values are for high purity samples and are based on the most recent measurements. These values are considered accurate to within ±3% and are represented approximately by the following equation:

$$\Delta L/L_0 = -1.036 + 3.190 \times 10^{-3}\, T + 1.138 \times 10^{-6}\, T^2 + 1.553 \times 10^{-10}\, T^3 \qquad (150\text{-}900\ K)$$

The tabulated values for the coefficient of thermal expansion are based on the selected experimental data. These values are considered accurate to about ±10%.

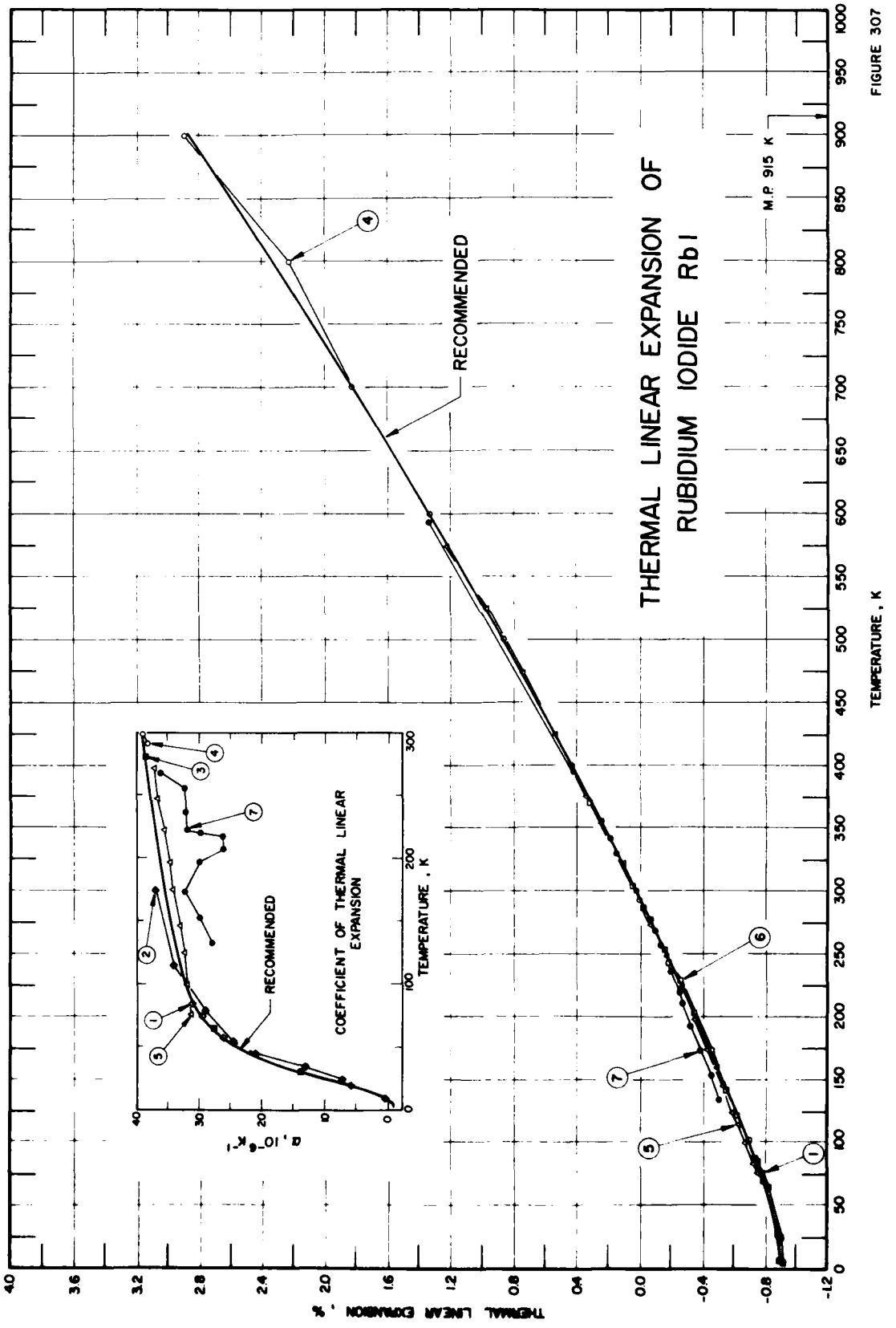

THERMAL LINEAR EXPANSION OF
RUBIDIUM IODIDE RbI
RECOMMENDED
M.P. 915 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
α , 10⁻⁶ K⁻¹
TEMPERATURE , K

FIGURE 307

SPECIFICATION TABLE 307. THERMAL LINEAR EXPANSION OF RUBIDIUM IODIDE RbI

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	479	White, G. K.	1965	C	4-283		Dimensions: cylindrical, 2 cm diameter, ~5 cm long; specimen obtained from Semi-Elements, Inc., of Pennsylvania; data smoothed by author; this curve is here reported utilizing other coefficients of thermal linear expansion from 85 K to 283 K for integration purposes.
2*	755	Schuele, D. E.	1963	X	25-175		Single crystal, plane (642) used; Fe radiation (λ = 1.93597 Å); crystal supplied by Professor W. B. Daniels of Princton University; coefficient of thermal linear expansion recorded; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
3*	623	White, G. K. and Collins, J. G.	1973	E	2-283		Dimensions: 20 mm diameter, 50.8 mm long; specimen obtained from Semi-Elements of Pennsylvania; partial data extracted from White (1965); this curve is here reported utilizing other coefficients of thermal linear expansion from 85 K to 283 K for integration purposes.
4	625	Srivastava, K. K. and Merchant, H. D.	1972	X	293-900		No details given.
5	626	Rapp, J. E. and Merchant, H. D.	1972	L	76-575		Crystal orientation was <1, 0, 0>; dimensions 5 x 5 x 50 mm.
6	809	Urvas, O.	1971	X	239-370		Crystal grown in author's laboratory by Kyropoulov method; salt was <<Suprapur 7619>> quality manufactured by E. Mereck, AG Darmstadt, W. Germany; lattice parameter reported at 294.4 K as 7.34693 Å; 7.34653 Å at 293 K determined by graphical interpolation; smoothed data.
7	663	Von Trost, K. F.	1963		134-594		No details given.

* Not shown in figure.

DATA TABLE 307. THERMAL LINEAR EXPANSION OF RUBIDIUM IODIDE RbI

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
4	-0.895*
5	-0.895
6	-0.895*
7	-0.895*
8	-0.895*
10	-0.895*
12	-0.895*
14	-0.894*
16	-0.894*
18	-0.893*
20	-0.892*
22	-0.891*
24	-0.889*
26	-0.887
28	-0.885*
30	-0.882*
57.5	-0.826*
65	-0.806
75	-0.777
85	-0.746*
283	-0.039*
CURVE 2*, †, ‡	
25	0.000
35	0.010
45	0.027
55	0.050
65	0.076
80	0.119
115	0.230
175	0.445
CURVE 3*, ‡	
2.462	-0.894
3.096	-0.894
3.180	-0.894
3.611	-0.894
3.690	-0.894
4.038	-0.894
4.069	-0.894
4.434	-0.894
4.896	-0.894
5.486	-0.894
6.105	-0.894
6.640	-0.894
7.143	-0.894
7.677	-0.894
8.261	-0.894
8.908	-0.894
9.608	-0.894
10.558	-0.894
11.409	-0.894
12.437	-0.894
13.712	-0.893
14.969	-0.893
16.244	-0.893
17.535	-0.892
18.974	-0.892
20.696	-0.891
22.599	-0.889
24.546	-0.888
26	-0.886
28	-0.884
30	-0.881
57.5	-0.826
65	-0.805
75	-0.777
85	-0.746
283	-0.039
CURVE 4‡	
293	0.000
300	0.027
400	0.433
500	0.869
600	1.335
700	1.830
800	2.350
900	2.894
CURVE 5‡	
76	-0.752
83	-0.730
100	-0.675
114	-0.631
124	-0.598
146	-0.526
174	-0.432
197	-0.352
223	-0.260
248	-0.169
273	-0.076
293	0.000
298	0.019
322	0.113
375	0.327
424	0.534
474	0.752
524	0.976
551	1.099
575	1.210
CURVE 6	
5.7	-0.893
9.9	-0.893*
12.3	-0.891*
19.4	-0.893*
27.6	-0.886
41.8	-0.863*
50.6	-0.843*
59.1	-0.824*
69.8	-0.792
77.9	-0.769*
77.9	-0.764*
79.1	-0.763*
86.1	-0.742
91.2	-0.724
97.8	-0.708*
101.1	-0.693
105.5	-0.687*
112.1	-0.662*
117.3	-0.646*
122.2	-0.626
127.3	-0.610*
131.8	-0.595*
137.6	-0.578*
142.4	-0.558
147.4	-0.546*
152.4	-0.523*
157.6	-0.506*
163.0	-0.487*
167.8	-0.468*
173.0	-0.452
178.1	-0.436*
182.9	-0.418*
188.3	-0.401*
193.3	-0.381*
198.4	-0.363*
203.9	-0.342
208.8	-0.325*
213.9	-0.306*
218.8	-0.286*
224.0	-0.269*
229.0	-0.255
229.0	-0.249*
234.3	-0.232*
234.4	-0.232*
239.0	-0.215*
239.1	-0.216*
243.7	-0.199
243.8	-0.197*
248.7	-0.179*
253.6	-0.165*
253.6	-0.162
258.6	-0.139*
263.4	-0.119*
263.4	-0.120*
267.7	-0.109*
273.7	-0.079*
277.3	-0.062
282.2	-0.049*
285.2	-0.036*
294.4	0.005*
295.2	0.010*
302.1	0.032*
303.6	0.041
317.5	0.091*
333.4	0.158*
340.9	0.194*
348.2	0.217*
355.0	0.248
361.7	0.271*
367.6	0.305*
370.6	0.326
CURVE 7‡	
134	-0.507
154	-0.449
173	-0.389
192	-0.329
212	-0.273
218	-0.257*
220	-0.251
223	-0.242*
236	-0.200
257	-0.131
268	-0.093
293	0.000*
330	0.147
342	0.197
395	0.422
594	1.344

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 307. COEFFICIENT OF THERMAL LINEAR EXPANSION OF RUBIDIUM IODIDE RbI

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
4	-0.014*
5	-0.026
6	-0.04*
7	-0.029*
8	0.015*
10	0.31
12	0.9*
14	1.8*
16	3.0*
18	4.4*
20	6.0
22	7.6*
24	9.2*
26	10.8*
28	12.5*
30	14.1
57.5	26.5
65	28.0*
75	29.8
85	31.25
CURVE 2‡	
25	7.1
35	13.3
45	21.1
55	24.8
65	27.7
80	29.3
115	34.3
175	37.3
CURVE 3‡	
2.462	-0.0019*
3.096	-0.0050*
3.180	-0.0062*
3.611	-0.0089*
3.690	-0.0116*
4.038	-0.0137*
4.069	-0.0132*
4.434	-0.0187*
4.896	-0.0268*
5.486	-0.0364*
6.105	-0.0409*
6.640	-0.0389*
7.143	-0.0291*
7.677	-0.0055*
8.261	0.0387*
8.908	0.1081*
9.608	0.2263*
10.558	0.4251*
11.409	0.6462*
12.437	1.036*
13.712	1.635*
14.969	2.306*
16.244	3.129*
17.535	4.131*
18.974	5.176*
20.696	6.532*
22.599	7.779*
24.546	9.701*
26.0	10.80*
28.0	12.50*
30.0	14.10
57.5	26.30
65	27.80
75	29.80*
85	31.13*
283	38.90
CURVE 4*,‡	
293	38.6
300	39.1
400	42.1
500	45.1
600	48.1
700	50.8
800	53.3
900	55.4
CURVE 5‡	
76	31.5
83	32.0*
100	32.0
114	32.1*
124	32.5
146	33.1
174	34.3
197	34.9
223	35.9
248	36.9
273	37.6
293	38.4*
298	38.6*
322	39.6*
375	41.4*
424	42.9*
474	44.3*
524	45.5*
551	45.8*
575	46.2*
CURVE 7‡	
134	28.3
154	30.0
173	32.7
192	30.3
212	26.3
218	26.5
220	30.0
223	32.1
236	32.6
257	32.7
268	36.3
293	38.5*
330	40.9*
342	42.1*
395	43.0*
594	49.6*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0 = 0$.

SPECIFICATION TABLE 308. THERMAL LINEAR EXPANSION OF SILVER IODIDE AgI

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	160	Schaake, H. F.	1969	X	60-298	Specimen 1	Material S-178 from Fisher; heated in test tube to above its melting point, quenched by pouring into water, dried, ground; amount of grinding proportional to amount of cubic phase produced (up to 50%); placed in copper holder, annealed 10 min at 423 K; quenched by placing copper on ice; specimen turned yellow during quenching; lattice parameter reported at 298 K as 6.49545 Å; 6.49547 Å at 293 K determined by graphical interpolation.
2*	160	Schaake, H. F.	1969	X	4.2-293	Specimen 2	Similar to the above specimen; lattice parameter reported at 293 K as 6.4955 Å.
3*	160	Schaake, H. F.	1969	X	4.2-273		Similar to the above specimen except final quenching with dry ice; lattice parameter reported at 273 K as 6.4961 Å; 6.4958 Å at 293 K determined by graphical extrapolation.
4*	808	Jansson, B. and Sjöblom, C. A.	1973		464-765	β-phase	Dimensions: cylindrical, 11.2 mm diameter x 30-40 mm long; made from potassium iodide and silver nitrate (from E. Merck, AG Darmstadt, Germany) according to Cohen and von Dabbenburg (1928); density 5.22-5.469 g cm^{-2} at 293 K; reported error ±4%; expansion measured on first heating.
5*	808	Jansson, B. and Sjöblom, C. A.	1973		441-767	β-phase	The above specimen; expansion measured on first cooling.
6*	808	Jansson, B. and Sjöblom, C. A.	1973		454-774	β-phase	The above specimen; expansion measured on second heating.
7*	808	Jansson, B. and Sjöblom, C. A.	1973		490-788	β-phase	The above specimen; expansion measured on second cooling.

* No figure given.

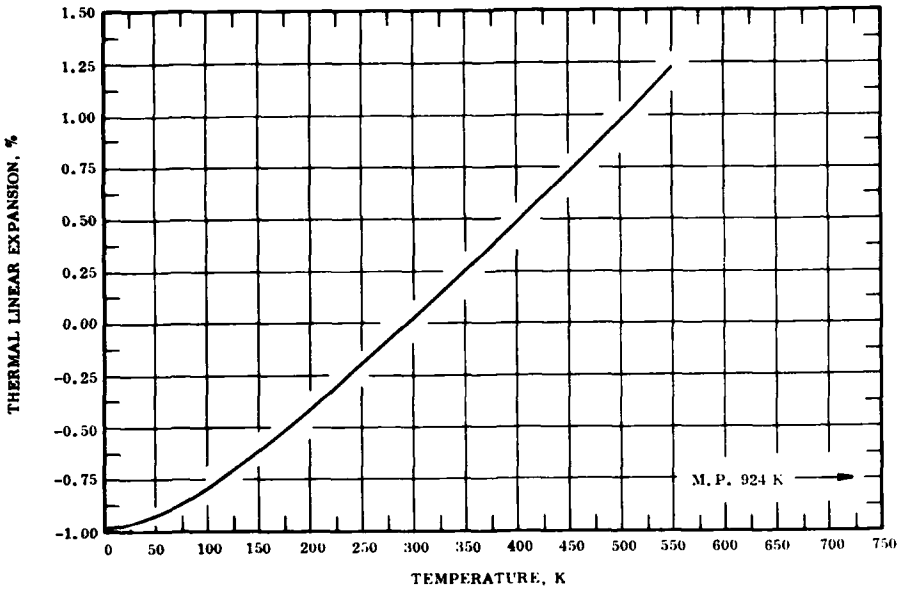
DATA TABLE 308. THERMAL LINEAR EXPANSION OF SILVER IODIDE AgI

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
60	0.0328
77.4	0.0158
90	0.0127
112	0.0112
131	0.0112
298	-0.0003
CURVE 2*	
4.2	0.0801
32	0.0585
50	0.0400
68	0.0200
77.4	0.0200
90	0.0031
115	0.0031
132	-0.0015
153	-0.0015
178	0.0015
194.5	0.0077
220	0.0062
241	0.0092
273	-0.0062
293	0.0000
CURVE 3*	
4.2	0.0961
31	0.0499
50	0.0438
60	0.0253
77.4	0.0083
102	0.0130
122	0.0237
152	0.0007
162	-0.0101
194.5	-0.0040
240	0.0099
273	0.0037
CURVE 4*	
464	1.047
476	1.054
489	1.062
502	1.079
524	1.091
CURVE 4 (cont.)*	
535	1.111
548	1.140
564	1.168
575	1.193
585	1.227
600	1.259
613	1.291
624	1.319
638	1.342
648	1.363
658	1.380
666	1.405
677	1.429
691	1.464
703	1.484
715	1.503
727	1.526
739	1.546
751	1.566
765	1.580
CURVE 5*	
441	0.299
457	0.348
470	0.389
484	0.429
497	0.464
510	0.516
522	0.552
532	0.596
550	0.648
564	0.695
589	0.785
601	0.830
617	0.884
630	0.935
644	0.984
656	1.036
667	1.082
680	1.131
691	1.185
704	1.241
717	1.310
730	1.364
742	1.424
754	1.500
CURVE 5 (cont.)*	
767	1.552
CURVE 6*	
454	0.311
466	0.346
480	0.378
494	0.425
509	0.464
521	0.513
534	0.557
547	0.598
553	0.622
560	0.650
566	0.654
581	0.707
593	0.745
607	0.787
618	0.830
631	0.865
644	0.902
658	0.952
671	0.992
688	1.047
700	1.088
713	1.128
727	1.168
736	1.198
749	1.232
762	1.262
774	1.291
CURVE 7*	
490	0.098
502	0.133
523	0.197
537	0.247
551	0.287
562	0.335
576	0.380
588	0.422
598	0.462
615	0.521
627	0.565
642	0.614
659	0.675
CURVE 7 (cont.)*	
672	0.727
684	0.782
695	0.832
710	0.885
720	0.938
733	0.989
745	1.056
759	1.121
777	1.210
788	1.274

* No figure given.

FIGURE AND TABLE NO. 309R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF SODIUM IODIDE NaI



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
2	-0.981	0.005
5	-0.981	0.06
10	-0.981	0.70
15	-0.980	2.5
20	-0.978	4.9
25	-0.975	7.8
50	-0.939	21.0
75	-0.874	30.0
100	-0.794	34.5
150	-0.612	39.1
200	-0.401	42.0
250	-0.187	43.7
293	0.000	44.7
350	0.257	45.3
400	0.486	46.5
450	0.728	49.0
500	0.977	52.2
550	1.249	56.7

REMARKS

The recommended values are based on curves 1 and 6 (2-290 K) and curve 8 (70-566 K) which are consistent with one another and follow the general trend for other iodides. The data reported in curves 2 to 4 are considerably lower, probably due to thallium impurity. The recommended values are considered accurate to within ±3% at temperatures below 293 K and ±5% above 293 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -1.251 + 4.347 \times 10^{-3}\, T - 9.722 \times 10^{-7}\, T^2 + 2.406 \times 10^{-9}\, T^3 \qquad (150\text{-}550\ K)$$

The tabulated values for the coefficient of thermal expansion are derived from the selected experimental data and are considered accurate to about ±7%.

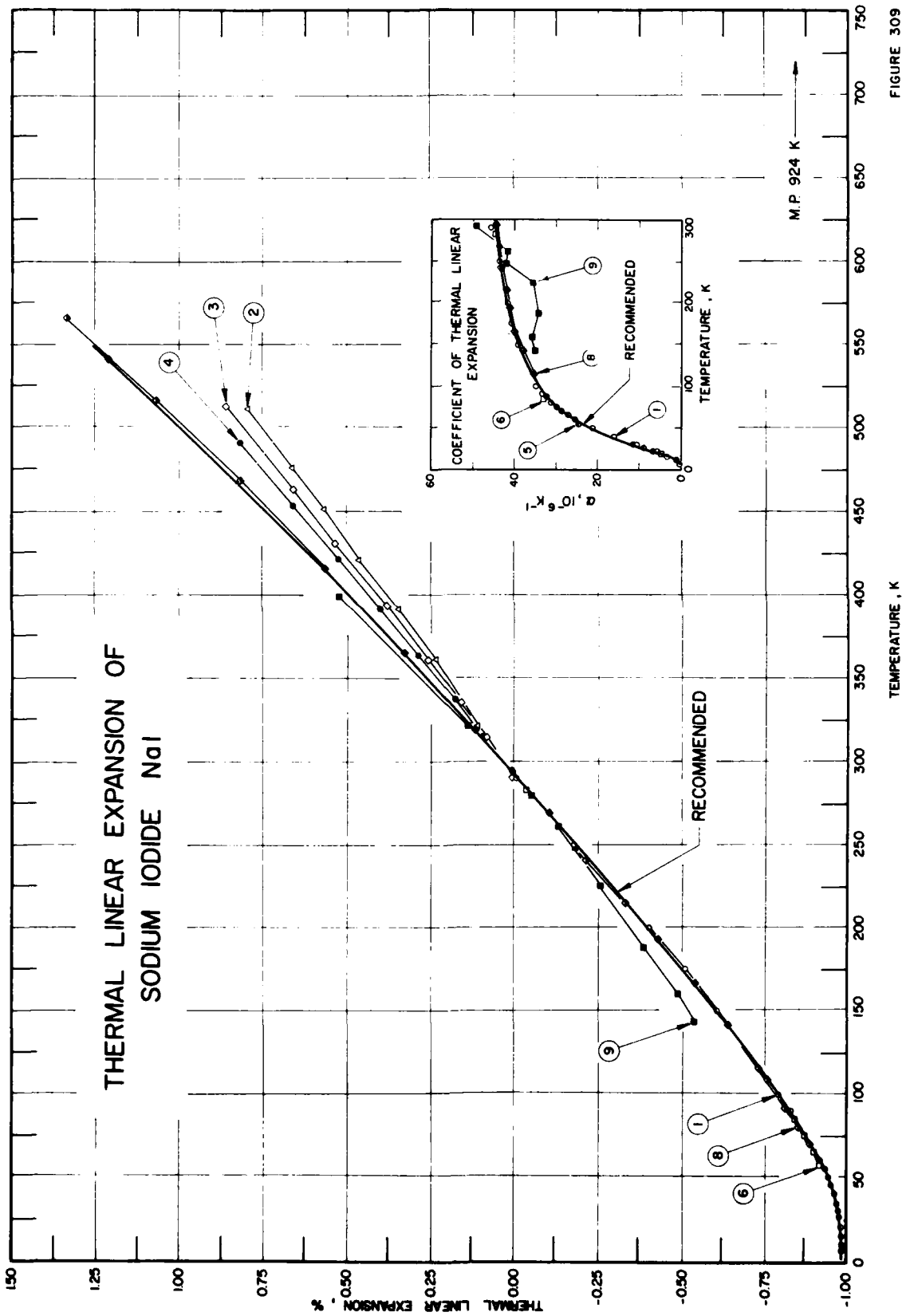

THERMAL LINEAR EXPANSION OF
SODIUM IODIDE NaI
RECOMMENDED
M.P 924 K
TEMPERATURE , K
THERMAL LINEAR EXPANSION , %
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
TEMPERATURE , K
α ,10⁻⁶ K⁻¹

FIGURE 309

SPECIFICATION TABLE 309. THERMAL LINEAR EXPANSION OF SODIUM IODIDE NaI

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	418	Meincke, P.A.M. and Graham, G.M.	1965	I	7-290		Crystal supplied by the Harshaw Chemical Co.; specimen 2.021 cm diameter with an axial hole of 1.27 cm diameter, and 5.08 cm long; warmed slowly from 5 K to 50 K and cooled again; data smoothed; reported error < 5%.
2	810	Bakradze, R.V., Kutsykovich, M.B., and Shumakov, Y.I.	1966	L	293-512		~0.00002 Tl; single crystal; cylindrical specimen 3 mm diameter and 50 mm long dried at 473 K beforehand.
3	810	Bakradze, R.V., et al.	1966	L	293-513		Similar to the above specimen except 0.41 Tl.
4	810	Bakradze, R.V., et al.	1966	L	295-491		Similar to the above specimen except 0.52 Tl.
5*	479	White, G.K.	1965	C	4-283		Cylindrical; 2.0 cm diameter, 5.08 cm long; optical quality from Harshaw Chemical Co. of Ohio; data smoothed by author; this curve is here reported utilizing other coefficients of thermal linear expansion from 85 K to 283 K for integration.
6	623	White G.K. and Collins, J.G.	1973	E	2-283		Dimensions: 20 mm diameter, 50.8 mm long; specimen obtained from Harshaw Chemical Co. of Ohio; first test; data reported was taken June 1969; this curve is here reported utlizing other coefficients of thermal linear expansion from 85 K to 283 K for integration.
7*	623	White, G.K. and Collins, J.G.	1973	E	2-21		The above specimen except second test and data reported was taken July 1969.
8	626	Rapp, J.E. and Merchant, H.D.	1972	L	70-566		Crystal orientation was (1, 0, 0); dimensions: 5 x 5 x 25 mm; smoothed data.
9	663	Von Trost, K.F.	1963		143-399		No details given.
10*	664	Whittemore, D.O.	1962	L	293, 593		Dimensions: cylinder, 1.27 cm diameter x 2.54 cm long; specimen made by pressing reagent grade chemicals in a steel mold at 703 kg/cm^{-2}; original length measured by micrometer to 2.54 mm; measurement taken by placing two cylinders end to end.

* Not shown in figure.

DATA TABLE 309. THERMAL LINEAR EXPANSION OF SODIUM IODIDE NaI

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1‡

T	$\Delta L/L_0$
7	-0.985
8	-0.985
9	-0.985
10	-0.985
11	-0.985
12	-0.985
13	-0.984
14	-0.984
15	-0.984
16	-0.984
17	-0.983
18	-0.983
19	-0.983
20	-0.982
22	-0.981
24	-0.980
26	-0.978
28	-0.977
30	-0.975
32	-0.973
34	-0.970
36	-0.968
38	-0.965
40	-0.962
45	-0.953
50	-0.943
55	-0.932
60	-0.920
70	-0.893
80	-0.863
90	-0.830
100	-0.796
150	-0.611
175	-0.516
200	-0.407
250	-0.192
290	-0.013

CURVE 2

T	$\Delta L/L_0$
293	0.000
323	0.104
362	0.241
392	0.348
421	0.453

CURVE 2 (cont.)

T	$\Delta L/L_0$
453	0.570
475	0.652
512	0.791

CURVE 3

T	$\Delta L/L_0$
293	0.000
314	0.077
335	0.155
362	0.257
393	0.377
432	0.530
463	0.653
513	0.857

CURVE 4

T	$\Delta L/L_0$
295	0.008
314	0.083
337	0.175
364	0.284
392	0.399
421	0.519
453	0.654
491	0.817

CURVE 5*, ‡

T	$\Delta L/L_0$
4	-0.982
5	-0.982
6	-0.982
7	-0.982
8	-0.982
10	-0.982
12	-0.982
14	-0.982
16	-0.981
18	-0.986
20	-0.979
22	-0.978
24	-0.977
26	-0.978
28	-0.974
30	-0.971
57.5	-0.923

CURVE 5 (cont.)*, ‡

T	$\Delta L/L_0$
65	-0.904
75	0.875
85	0.844
283	0.045

CURVE 6‡

T	$\Delta L/L_0$
2.315	-0.980
3.019	-0.980
3.583	-0.980
4.043	-0.980
4.440	-0.980
4.860	-0.980
5.288	-0.980
5.666	-0.980
6.014	-0.980
6.408	-0.980
6.838	-0.980
7.311	-0.980
7.880	-0.980
8.520	-0.980
9.221	-0.980
9.953	-0.980
10.749	-0.980
11.810	-0.980
13.081	-0.980
14.306	-0.979
15.518	-0.979
16.882	-0.979
18.467	-0.978
20.130	-0.977
21.907	-0.976
23.736	-0.975
25.518	-0.974
27.227	-0.973
28.842	-0.971
57.5	-0.922
65	-0.903
75	-0.874
85	-0.843
283	-0.045

CURVE 7*, †, ‡

T	$\Delta L/L_0$
2.899	0.000
3.563	0.009
4.014	0.021
4.430	0.036
4.859	0.057
5.291	0.085
5.672	0.117
6.017	0.154
6.407	0.206
6.835	0.276
7.306	0.371
7.871	0.521
8.515	0.748
9.216	1.073
9.953	1.523
10.738	2.144
11.768	3.218
13.025	5.010
14.259	7.354
15.486	10.306
16.846	14.354
18.441	20.202
20.091	27.538
21.746	36.277

CURVE 7 (cont.)*, †, ‡

T	$\Delta L/L_0$

CURVE 8‡

T	$\Delta L/L_0$
70	-0.887
80	-0.856
92	-0.817
98	-0.797*
108	-0.762
116	-0.734
142	-0.638
167	-0.540
193	-0.433
216	-0.336
242	-0.224
269	-0.106
293	0.000*
318	0.112
365	0.325
416	0.563
468	0.815
517	1.068
542	1.205
566	1.343

CURVE 9‡

T	$\Delta L/L_0$
143	-0.544
160	-0.487
188	-0.388
225	-0.262
249	-0.181
262	-0.131
280	-0.056
293	0.000*
322	0.135
397	0.518
399	0.529*

CURVE 10*

T	$\Delta L/L_0$
293	0.00
593	1.57

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 309. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SODIUM IODIDE NaI

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
7	0.16
8	0.29*
9	0.48*
10	0.65*
11	0.97*
12	1.28
13	1.64*
14	2.03*
15	2.43*
16	2.85*
17	3.28
18	3.75*
19	4.24*
20	4.71*
22	5.80
24	6.91*
26	7.93*
28	9.15*
30	10.27
32	11.41*
34	12.61*
36	13.81*
38	14.93*
40	16.00
45	18.84*
50	21.27
55	23.49*
60	25.30
70	28.64
80	31.23
90	33.23
100	34.78
150	39.46
175	40.82
200	41.90
250	43.95
290	45.54
CURVE 2*	
293	34.3
323	34.8
362	35.5
392	35.8
421	36.5
453	37.0
475	37.4
512	38.0
CURVE 3*	
293	36.5
314	37.0
335	37.5
362	38.1
393	38.8
432	39.6
463	40.3
513	41.2
CURVE 4*	
295	39.0
314	39.6
337	40.3
364	40.6
392	41.4
421	41.9
453	42.5
491	43.3
CURVE 5‡	
4	0.032*
5	0.064*
6	0.11*
7	0.20*
8	0.33*
10	0.74*
12	1.38*
14	2.1*
16	3.0*
18	4.0*
20	5.1*
22	6.2
24	7.3*
26	8.6
28	9.7*
30	10.8
57.5	24.5
65	27.3
75	30.0
85	32.2
283	45.1
CURVE 6‡	
2.315	0.0061*
3.019	0.0117*
3.583	0.0234*
4.043	0.0319*
4.440	0.0434*
4.860	0.0567*
5.288	0.0754*
5.666	0.0947*
6.014	0.1184*
6.408	0.1410*
6.838	0.1840*
7.311	0.2310*
7.880	0.3041*
8.520	0.4000*
9.221	0.5330*
9.953	0.6870*
10.749	0.9010*
11.810	1.2110*
13.081	1.6850*
14.306	2.1570*
15.518	2.6510*
16.882	3.3670*
18.467	4.0820*
20.130	4.9400
21.907	5.8570*
23.736	6.8740*
25.518	7.7980*
27.227	8.7250*
28.842	9.5920*
57.500	24.5000*
65	27.1000*
75	29.80*
85	32.15
283	44.60
CURVE 7‡	
2.899	0.0092
3.563	0.0189
4.014	0.0329
4.430	0.0399
4.859	0.0572
5.291	0.0742
5.672	0.0914
6.017	0.1209
6.407	0.1472
6.835	0.1806
7.306	0.2245
7.871	0.3066
8.515	0.3980
9.216	0.5290
9.953	0.6930
10.738	0.8880*
11.768	1.1980
13.025	1.6530
14.259	2.1450
15.486	2.6670
16.846	3.2860
18.441	4.0470
20.091	4.8450
21.746	5.7160
CURVE 8‡	
70	29.9*
80	31.3*
92	33.2*
98	35.1*
108	35.0*
116	35.5
142	38.2
167	40.1
193	41.9
216	42.6
242	43.5
269	43.9
293	44.6
318	45.0*
365	45.8*
416	47.3*
468	49.6*
517	53.6*
542	56.0*
566	59.6*
CURVE 9‡	
143	31.2
160	35.2
188	35.7
225	32.2
249	35.5
262	42.0
280	41.5
293	44.2*
32[illegible]	49.0*
397	53.1*
399	52.2*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 310. THERMAL LINEAR EXPANSION OF THALLIUM IODIDE TlI

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	811	Samara, G.A., Walter, L.C., and Northrop, D.A.	1967	X	295.4-443.9		Powdered sample measured at 1 bar; copper K-α radiation used (204) (024) and (220) peaks of the orthorhombic phase utilized for determining lattice parameter; expansion measured along a-axis; lattice parameter reported at 295.4 K as 4.5811 Å; 4.5810 Å at 293 K determined by graphical extrapolation.
2*	811	Samara, G.A., et al.	1967	X	296-444.4		The above specimen; expansion measured along b-axis; lattice parameter reported at 296 K as 5.2480 Å; 5.2470 Å at 293 K determined by graphical extrapolation.
3*	811	Samara, G.A., et al.	1967	X	295.8-444.5		The above specimen; expansion measured along c-axis; lattice parameter reported at 295 K as 12.9136 Å; 12.9117 Å at 293 K determined by graphical extrapolation.
4*	811	Samara, G.A., et al.	1967	X	433-567		Similar to the above specimen except cubic phase; lattice parameter determined by (211) peak; this curve is here reported using 433 K as the reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 310. THERMAL LINEAR EXPANSION OF THALLIUM IODIDE TlI

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
295.4	0.002
316.3	0.026
325.6	0.052
337.5	0.072
351.3	0.096
356.5	0.096
370.0	0.120
392.8	0.151
404.7	0.183
413.6	0.194
424.8	0.229
431.4	0.238
443.9	0.258

CURVE 2*

T	$\Delta L/L_0$
296	0.019

CURVE 2 (cont.)*

T	$\Delta L/L_0$
315.8	0.151
325.8	0.183
337.5	0.278
351.4	0.337
357.0	0.383
370.1	0.446
391.9	0.591
405.1	0.669
413.6	0.705
425.7	0.802
431.5	0.839
444.4	0.926

CURVE 3*

T	$\Delta L/L_0$
295.8	0.015
315.7	0.120

CURVE 3 (cont.)*

T	$\Delta L/L_0$
325.3	0.152
337.2	0.228
351.0	0.253
357.3	0.297
369.7	0.387
391.8	0.463
405.1	0.551
413.2	0.593
425	0.630
430.5	0.647
444.5	0.771

CURVE 4*, †

T	$\Delta L/L_0$
443	0.000
445	0.083
457	0.146

CURVE 4 (cont.)*, †

T	$\Delta L/L_0$
464	0.165
485	0.285
488	0.283
489	0.325
489	0.306
497	0.342
499	0.342
512	0.413
514	0.413
529	0.502
531	0.505
544	0.580
544	0.573
554	0.629
567	0.705
567	0.700

* No figure given.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

SPECIFICATION TABLE 311. THERMAL LINEAR EXPANSION OF MISCELLANEOUS IODIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	800	Kovalevskaya, Y.A. and Strelkov, P.G.	1966	L	25-285	CdI_2	Cadmium iodide; single crystal grown by Stockbarger method; sample cut out in the form of rectangular parallelepipeds with linear dimension about 5-10 mm; expansion measured in plane of layers; reported error 1.5-4%.
2*	800	Kovalevskaya, Y.A. and Strelkov, P.G.	1966	L	22-274	CdI_2	Cadmium iodide; the above specimen except expansion measured perpendicular to layers; reported error 1.5-4%.
3*	160	Schaake, H.F.	1969	X	4.2-299	CuI	Copper iodide; material C-465, from Fisher; powder ground to <325 mesh; 10% iridium added for calibration; pressed into copper sample holder, annealed 2 hr at 473 K; lattice parameter reported at 298.16 K as 6.0517 Å; 6.0512 Å at 293 K determined by graphical interpolation.
4*	632	Bridgman, P.W.	1932		303,348	CuI	Copper iodide; dimension: cylindrical, 0.937 cm diameter x 0.937-1.27 cm long; pressed specimen; expansion measured by lever piezometer.
5*	295	Hsu, Y.T.	1967	X	291-397	HgI_2	Mercury diiodide; reagent grade powder of tetragonal crystals placed in 0.3 mm diameter capillary; expansion measured along a-axis; lattice parameter reported at 291 K as 4.363 Å; 4.365 Å at 293 K determined by graphical interpolation.
6*	295	Hsu, Y.T.	1967	X	291-397	HgI_2	Mercury diiodide; the above specimen; expansion measured along c-axis; lattice parameter reported at 291 K as 12.394 Å; 12.395 Å at 293 K determined by graphical interpolation.
7*	295	Hsu, Y.T.	1967	X	411-461	HgI_2	Mercury diiodide; similar to the above specimen except orthorhombic; expansion measured along a-axis; lattice parameter reported at 411 K as 4.709 Å; 4.703 Å at 293 K determined by graphical extrapolation.
8*	295	Hsu, Y.T.	1967	X	411-461	HgI_2	Mercury diiodide; the above specimen; expansion measured along b-axis; lattice parameter reported at 411 K as 7.325 Å; 7.335 Å at 293 K determined by graphical extrapolation.
9*	295	Hsu, Y.T.	1967	X	411-461	HgI_2	Mercury diiodide; the above specimen; expansion measured along c-axis; lattice parameter reported at 411 K as 13.848 Å; 13.660 Å at 293 K determined by graphical extrapolation.
10*	295	Hsu, Y.T.	1967	X	293-628	PbClI	Lead chloroiodide; powder specimen of orthorhombic crystals prepared from reagent grade materials; placed in 0.3 mm capillary; expansion measured along a-axis; lattice parameter reported at 293 K as 5.000 Å.
11*	295	Hsu, Y.T.	1967	X	293-628	PbClI	Lead chloroiodide; the above specimen; expansion measured along b-axis; lattice parameter reported at 293 K as 9.546 Å.
12*	295	Hsu, Y.T.	1967	X	293-608	PbClI	Lead chloroiodide; the above specimen; expansion measured along c-axis; lattice parameter reported at 293 K as 11.451 Å.
13*	295	Hsu, Y.T.	1967	X	293-662	PbI_2	Lead diiodide; reagent grade powdered hexagonal crystals; expansion determined by average of lattice parameters reported; expansion measured along a-axis; lattice parameter reported at 292 K as 4.542 Å.
14*	295	Hsu, Y.T.	1967	X	293-662	PbI_2	Lead diiodide; the above specimen; expansion determined by average of lattice parameters reported; expansion measured along c-axis; lattice parameter reported at 292 K as 6.979 Å.
15*	812	Kovtun, S.F. and Ul'yanov, R.A.	1963	L	74-1285	TiI_4	Titanium tetraiodide; no details given.

* No figure given.

SPECIFICATION TABLE 311. THERMAL LINEAR EXPANSION OF MISCELLANEOUS IODIDES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
16*	813	Kovtun, S. F. and Ul'yanov, R. A.	1964		273-1281	TiI_4	Titanium tetraiodide; 99.94 titanium iodide; specimen 10 mm in diameter; measured in vacuum of 1×10^{-5} mm Hg with heating rate of 1 K min^{-1}.
17*	322	Cobes, L. S., Ballard, S. S., and McCarthy, K. A.	1951	L	223-473	TlBr + TlI	Thallium bromide + thallium iodide; bar specimen; obtained from the Engineer Research and Development Laboratories.
18*	322	Cobes, L. S., et al.	1951	L	223-473	TlBr + TlI	Thallium bromide + thallium iodide; the above specimen, average data.
19*	665	Johnson, D. W.	1967		293, 373	TlBr + TlI	Thallium bromide + thallium iodide; no details given.

* No figure given.

DATA TABLE 311. THERMAL LINEAR EXPANSION OF MISCELLANEOUS IODIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*,‡	
25	-0.540
27	-0.539
29	-0.537
31	-0.535
31	-0.535
35	-0.531
36	-0.530
40	-0.525
42	-0.523
46	-0.518
48	-0.515
55	-0.506
57	-0.503
64	-0.493
64	-0.493
72	-0.480
75	-0.475
78	-0.470
82	-0.463
87	-0.454
91	-0.446
98	-0.434
104	-0.422
106	-0.413
111	-0.408
117	-0.397
123	-0.385
125	-0.381
132	-0.367
133	-0.365
142	-0.346
148	-0.333
150	-0.329
159	-0.310
162	-0.304
168	-0.291
180	-0.265
184	-0.256
190	-0.243
191	-0.241
195	-0.232
201	-0.219
203	-0.215
210	-0.199
212	-0.194
213	-0.192

T	$\Delta L/L_0$
CURVE 1 (cont.)*,‡	
213	-0.192
216	-0.185
221	-0.174
224	-0.167
232	-0.148
234	-0.143
236	-0.138
244	-0.119
248	-0.110
251	-0.103
254	-0.095
259	-0.083
259	-0.083
262	-0.076
268	-0.062
273	-0.050
273	-0.050
279	-0.035
283	-0.025
285	-0.020
CURVE 2*,‡	
22	-0.845
27	-0.835
30	-0.829
32	-0.825
32	-0.825
34	-0.821
35	-0.819
36	-0.817
36	-0.817
39	-0.810
43	-0.801
44	-0.799
49	-0.788
54	-0.777
54	-0.777
56	-0.772
59	-0.764
60	-0.726
62	-0.757
68	-0.741
70	-0.735
77	-0.716
81	-0.705

T	$\Delta L/L_0$
CURVE 2 (cont.)*,‡	
81	-0.705
85	-0.694
85	-0.694
87	-0.689
89	-0.683
93	-0.672
94	-0.669
97	-0.660
103	-0.643
108	-0.628
119	-0.594
123	-0.582
128	-0.566
129	-0.563
136	-0.542
139	-0.532
147	-0.507
149	-0.500
149	-0.500
158	-0.472
160	-0.465
169	-0.436
179	-0.403
180	-0.400
191	-0.363
200	-0.333
211	-0.295
221	-0.261
232	-0.222
243	-0.183
251	-0.154
256	-0.136
263	-0.110
273	-0.073
274	-0.070
CURVE 3*	
4.2	-0.374
20	-0.374
40	-0.373
77.4	-0.350
127	-0.269
160	-0.214
194.5	-0.165
236	-0.0919

T	$\Delta L/L_0$
CURVE 3 (cont.)*	
273.2	-0.0258
298.6	0.0073
299	0.0089
CURVE 4*	
303	0.024
348	0.135
CURVE 5*	
291	-0.046
294	0.023
335	0.206
397	0.321
CURVE 6*	
291	-0.008
294	0.000
335	0.161
397	0.323
CURVE 7*	
411	0.128
435	0.170
454	0.276
461	0.361
CURVE 8*	
411	-0.136
435	-0.164
454	-0.191
461	-0.205
CURVE 9*	
411	1.376
435	1.676
454	1.977
461	1.977

T	$\Delta L/L_0$
CURVE 10*	
293	0.000
319	0.060
337	0.120
379	0.140
403	0.280
453	0.480
494	0.580
503	0.700
523	0.800
560	1.020
608	1.240
628	1.280
CURVE 11*	
293	0.000
319	0.000
339	0.063
379	0.314
403	0.576
453	0.660
494	0.702
503	0.817
523	0.859
560	0.911
608	1.226
628	1.488
CURVE 12*	
293	0.000
319	0.087
337	0.192
379	0.332
403	0.489
453	0.559
494	0.672
503	0.803
523	0.873
560	0.969
608	1.004
CURVE 13*	
292	0.000
309	0.110

T	$\Delta L/L_0$
CURVE 13 (cont.)	
360	0.264
405	0.617
443	0.947
461	0.903
520	0.881
553	1.035
568	1.277
602	1.365
643	1.585
662	1.805
CURVE 14	
292	0.000
309	0.115
360	0.315
405	0.401
443	0.416
461	0.588
520	0.774
553	0.802
568	0.802
602	0.845
643	1.017
662	1.132
CURVE 15	
74	-0.166
173	-0.099
275	-0.025
294	0.002
375	0.070
475	0.169
576	0.263
675	0.362
776	0.468
878	0.563
975	0.677
1074	0.792
1172	0.910
1273	1.003
1285	1.02

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 311. THERMAL LINEAR EXPANSION OF MISCELLANEOUS IODIDES (continued)

T	$\Delta L/L_0$
CURVE 16*	
273	-0.013
303	0.007
473	0.157
595	0.282
671	0.357
717	0.407
803	0.497
933	0.652
979	0.702
1003	0.737
1067	0.812
1127	0.867
1137	0.887
1155	0.897
1171	0.917
1187	0.922
1209	0.937
1239	0.982
1281	1.027
CURVE 17*,‡	
223	-0.423
233	-0.362
253	-0.239
273	-0.118
293	0.000
313	0.116
333	0.232
353	0.348
373	0.464
393	0.577
413	0.697
433	0.817
453	0.937
473	1.037
CURVE 18*	
223	-0.427
293	0.000
373	0.464
473	1.026
CURVE 19*	
293	0.000
373	0.464

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0 = 0$.

DATA TABLE 311. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS IODIDES

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1*	
25	6.9
27	9.2
29	8.0
31	10.0
31	9.6
35	11.2
36	10.8
40	11.6
42	12.4
46	13.2
48	13.9
55	13.9
57	14.1
64	15.7
64	16.4
72	27.0
75	16.6
78	17.7
82	17.8
87	17.8
91	18.3
98	18.5
104	19.0
106	19.8
111	19.9
117	18.4
123	20.4
125	20.4
132	20.7
133	20.9
142	21.1
148	21.2
150	20.7
159	21.5
162	21.1
168	21.6
180	21.5
184	22.1
190	22.4
191	21.4
195	22.2
201	21.3
203	22.9
210	22.8
212	21.5
213	23.2

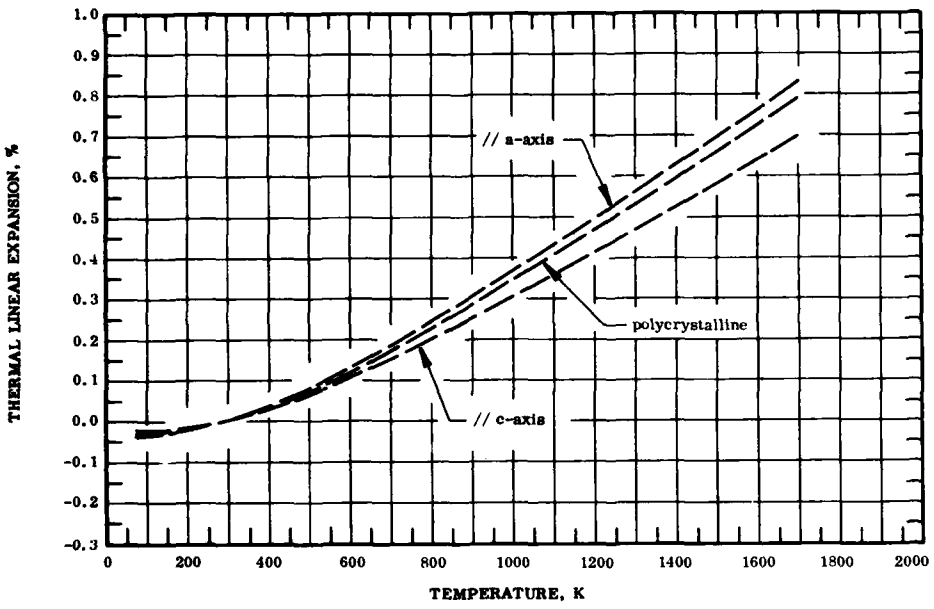
T	α
CURVE 1 (cont.)*	
213	22.3
216	23.1
221	22.7
224	23.9
232	23.7
234	23.7
236	22.7
244	24.3
248	24.3
251	23.2
254	24.1
259	23.7
259	24.2
262	24.5
268	23.6
273	24.6
273	25.0
279	24.4
283	25.0
285	25.0
CURVE 2*	
22	19.4
27	20.5
30	21.9
32	21.0
32	18.3
34	19.6
35	22.2
36	20.9
36	19.7
39	22.5
43	22.8
44	21.9
49	21.5
54	24.2
54	23.4
56	25.1
59	25.5
60	24.3
62	25.7
68	27.6
70	27.6
77	26.3
81	28.6

T	α
CURVE 2 (cont.)*	
81	27.9
85	28.5
85	27.2
87	28.5
89	27.5
93	29.2
94	28.3
97	29.4
103	28.7
108	30.7
119	30.9
123	30.4
128	31.9
129	31.0
136	30.3
139	31.6
147	31.9
149	32.3
149	31.8
158	32.5
160	31.5
169	32.7
179	33.4
180	32.8
191	33.8
200	33.7
211	34.5
221	34.9
232	35.5
243	35.8
251	36.6
256	36.3
263	36.8
273	36.3
274	37.1
CURVE 17*	
223	60
233	62
253	61
273	60
293	58
313	58
333	58
353	58

T	α
CURVE 17 (cont.)*	
373	58
393	57
413	57
433	57
453	57
473	57

* No figure given.

FIGURE AND TABLE NO. 312R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ALUMINUM NITRIDE AlN



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
75	-0.032	-0.025	-0.030	0.3
100	-0.031	-0.025	-0.039	0.5
150	-0.028	-0.022	-0.026	0.9
200	-0.020	-0.017	-0.019	1.9
250	-0.011	-0.009	-0.010	2.0
293	0.000	0.000	0.000	2.5
300	0.001	0.001	0.001	2.6
400	0.040	0.033	0.038	3.8
500	0.085	0.070	0.080	4.4
600	0.134	0.110	0.126	4.8
700	0.188	0.154	0.176	5.2
800	0.244	0.201	0.230	5.5
900	0.304	0.250	0.286	5.8
1000	0.366	0.302	0.345	6.0
1100	0.431	0.355	0.406	6.2
1200	0.497	0.411	0.468	6.3
1300	0.563	0.467	0.531	6.4
1400	0.631	0.524	0.595	6.4
1500	0.699	0.582	0.660	6.5
1600	0.766	0.640	0.724	6.5
1700	0.832	0.698	0.787	6.6

REMARKS

The provisional values for the axial thermal expansion are based on the most recent measurements (curves 4-7). The provisional values for the polycrystalline sample are calculated directly from these axial values. This result is recommended in preference to the reported experimental data for polycrystalline samples on the suspicion that these samples exhibit partial preferential orientation and are not randomly oriented. The tabulated values are considered accurate to within ± 8% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -8.679 \times 10^{-3} + 1.929 \times 10^{-4}\ T + 3.400 \times 10^{-7}\ T^2 - 7.969 \times 10^{-11}\ T^3$ (293-1700 K)

// c-axis: $\Delta L/L_0 = -7.006 \times 10^{-3} + 1.583 \times 10^{-4}\ T + 2.719 \times 10^{-7}\ T^2 - 5.834 \times 10^{-11}\ T^3$ (293-1700 K)

polycrystalline: $\Delta L/L_0 = -8.090 \times 10^{-3} + 1.806 \times 10^{-4}\ T + 3.176 \times 10^{-7}\ T^2 - 7.256 \times 10^{-11}\ T^3$ (293-1700 K)

The tabulated values for the coefficient of thermal expansion are derived primarily by differentiating the above equation for polycrystalline sample and are considered accurate to about ± 10%.

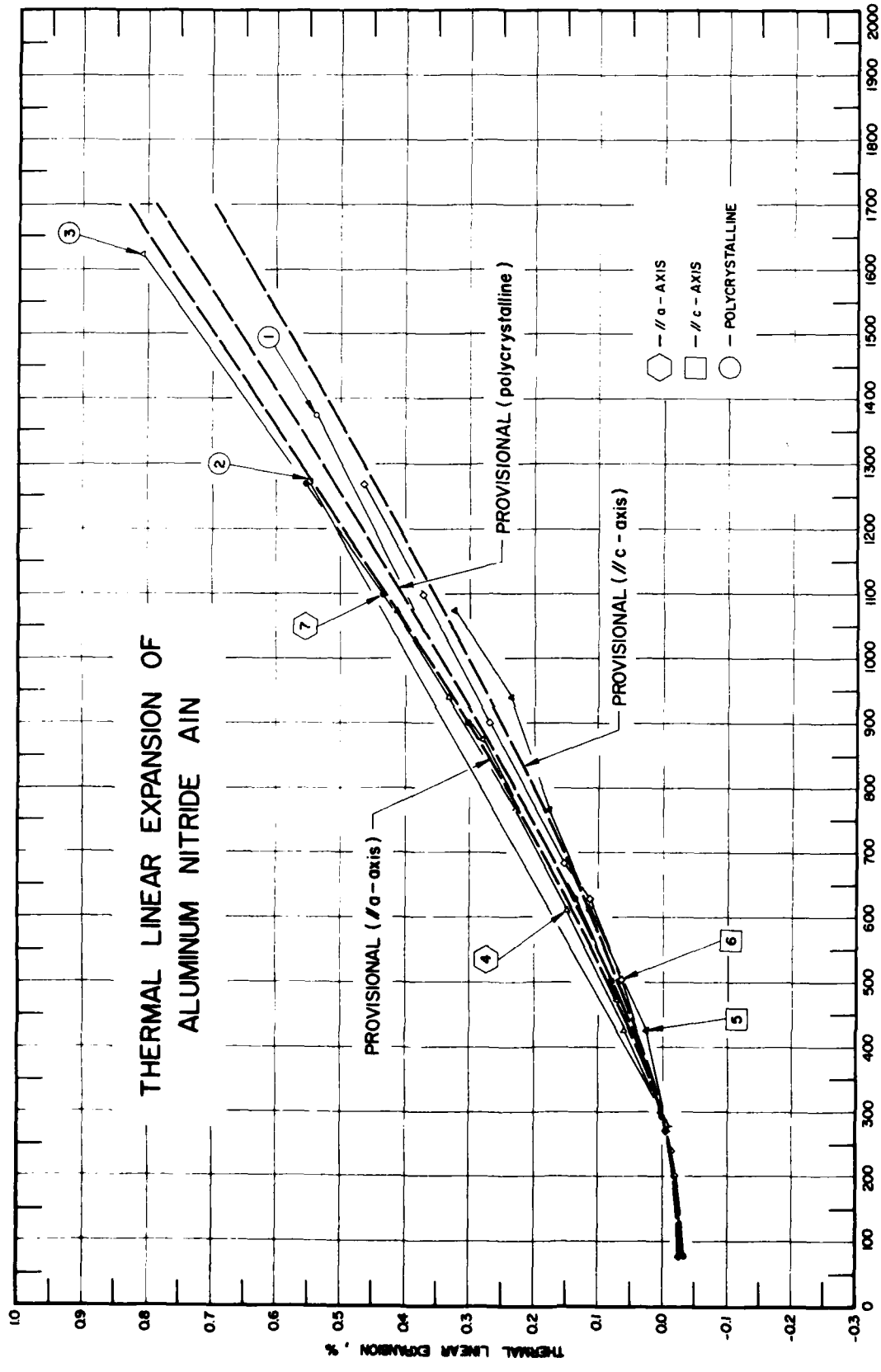

THERMAL LINEAR EXPANSION OF ALUMINUM NITRIDE AlN
PROVISIONAL (polycrystalline)
PROVISIONAL (// c - axis)
PROVISIONAL (// a - axis)
— // a - AXIS
— // c - AXIS
— POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 312

SPECIFICATION TABLE 312. THERMAL LINEAR EXPANSION OF ALUMINUM NITRIDE AlN

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	814	Struck, L.I., Dubovik, T.V., and Kazakov, V.K.	1967		293,1373		65.8 to 72.0 Al, 28 to 34.2 N; specimen prepared by action of nitrogen gas on aluminum powder at 1373-1473 K; bonded with solution of rubber in gasoline, pressed at 2000-4000 kg/cm^2 and dried at 433-473 K; sintered at 2073 K in nitrogen atm; porosity 15.0 to 18.0.
2	3	Steele, S.R., Pappis, J., Schilling, H., and Hagan, L.	1967		273,1273		Specimen deposited from a vapor at 1373 K.
3	815	Taylor, K.M. and Lenie, C.	1960	L	298-1623		64.8 Al, 32.8 N, 1.0 O, 0.4 Si, 0.2 C, 0.1 Fe; calculated composition 96.0 AlN, 2.1 Al_2O_3, 1.9 others; dimension 1.27 cm diameter x 7.62 cm; specimen prepared by direct combination of Alcoa's No. 101 atomized aluminum powder with 1% sodium fluoride, heated rapidly in purified nitrogen to 923 K, heated to max. of 2073 K over 40 hr period, dry ball milled to average particle size of approximately 5 μ, pressed into 3 in. diameter by 3 in. long rods at 5000 psi and 2273 K, cut into 0.5 in. diameter by 3 in. long rod, and ground; bulk density 3.20 g cm^{-3}; expansion measured parallel to direction of pressing.
4	504	Yim, W.M. and Paff, R.J.	1973	X	291-1073		Nongaseous impurities <0.02; dimension: cylindrical 0.3 mm diameter; the sample was ground to pass through a 325 mesh screen and placed into a 0.3 mm I.D. quartz capillary; expansion measured in 10^{-3} torr atm along the a-axis; lattice parameter reported at 293 K as 3.112 Å.
5	504	Yim, W.M. and Paff, R.J.	1973	X	291-1073		The above specimen; expansion measured along the c-axis; lattice parameter reported at 293 K as 4.980 Å.
6	818	Slack, G.A. and Bartram, S.F.	1974	X	77-1269		99$^+$ AlN, <1 O; grain size $\sim$5 μm; made from reacting high purity AH_2 with high purity NH_3; measurements along c-axis; lattice parameter reported at 297 K as 4.9788 Å.
7	818	Slack, G.A. and Bartram, S.F.	1974	X	77-1269		Similar to the above specimen except measurements along a-axis; lattice parameter reported at 297 K as 3.1105 Å.

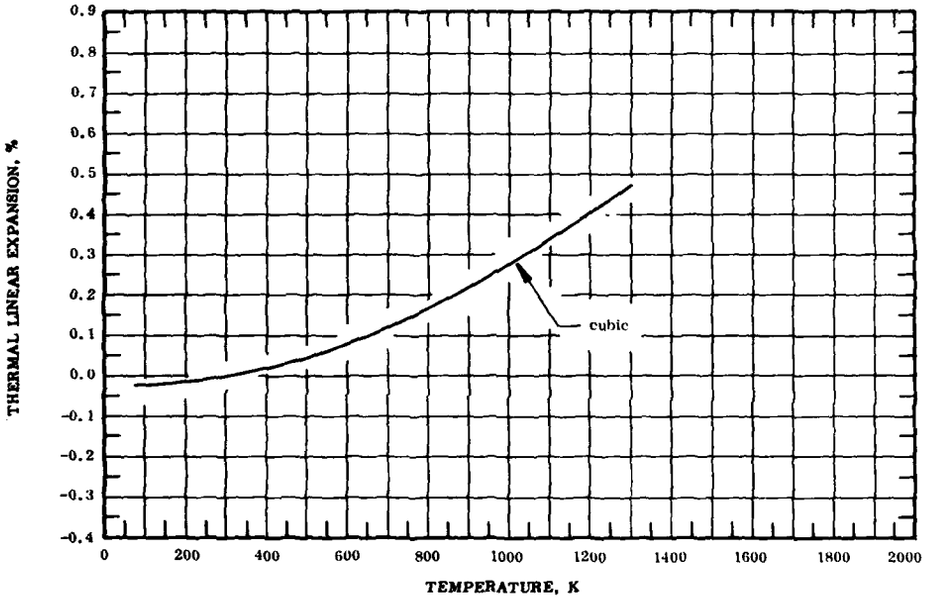
DATA TABLE 312. THERMAL LINEAR EXPANSION OF ALUMINUM NITRIDE AlN

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.00
1373	0.54
CURVE 2	
273	-0.011
1273	0.549
CURVE 3	
298	0.002
473	0.073
873	0.281
1273	0.553*
1623	0.810
CURVE 4	
291	-0.001*
427	0.060
611	0.150
767	0.230
939	0.333
1073	0.413
CURVE 5	
291	-0.001*
427	0.026
611	0.114
767	0.178
939	0.238
1073	0.325
CURVE 6	
77	-0.027
120	-0.024
160	-0.022
200	-0.019
240	-0.013
270	-0.007
503	0.064
628	0.114
683	0.153
901	0.269
CURVE 6 (cont.)	
1099	0.374
1269	0.464
CURVE 7	
77	-0.031
120	-0.028*
160	-0.026*
200	-0.023*
240	-0.017*
270	-0.010*
503	0.080
628	0.138
683	0.170
901	0.302
1099	0.437
1269	0.556

* Not shown in figure.

FIGURE AND TABLE NO. 313R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF BORON NITRIDE BN



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
75	-0.024	0.1
100	-0.023	0.7
150	-0.019	1.0
200	-0.014	1.2
250	-0.007	1.5
293	0.000	1.8
300	0.002	1.8
400	0.021	2.4
500	0.047	3.0
600	0.080	3.7
700	0.120	4.3
800	0.167	4.9
900	0.219	5.4
1000	0.276	5.9
1100	0.337	6.4
1200	0.403	6.8
1300	0.473	7.1

REMARKS

The recommended values are based on the data for cubic specimen (curves 11 and 47) and are considered accurate to within ± 5%. The measurements on the hot-pressed specimens (curves 20 to 45) indicate that the thermal linear expansion depends not only on the pressing direction but also on the location of sample in the original ingot, moisture content (curves 44 and 45), and the prior heat treatment. The recommended values are represented approximately by the following equation:

$$\Delta L/L_0 = -1.326 \times 10^{-3} - 1.278 \times 10^{-4}\, T + 4.911 \times 10^{-7}\, T^2 - 8.635 \times 10^{-11}\, T^3 \qquad (293\text{-}1300\ K)$$

The values for the coefficient of thermal linear expansion above 293 K are primarily derived by differentiating the above equation, and below 293 K, the values are extrapolated. These values are considered accurate to about ± 10% at temperatures above 293 K and ± 15% below 293 K.

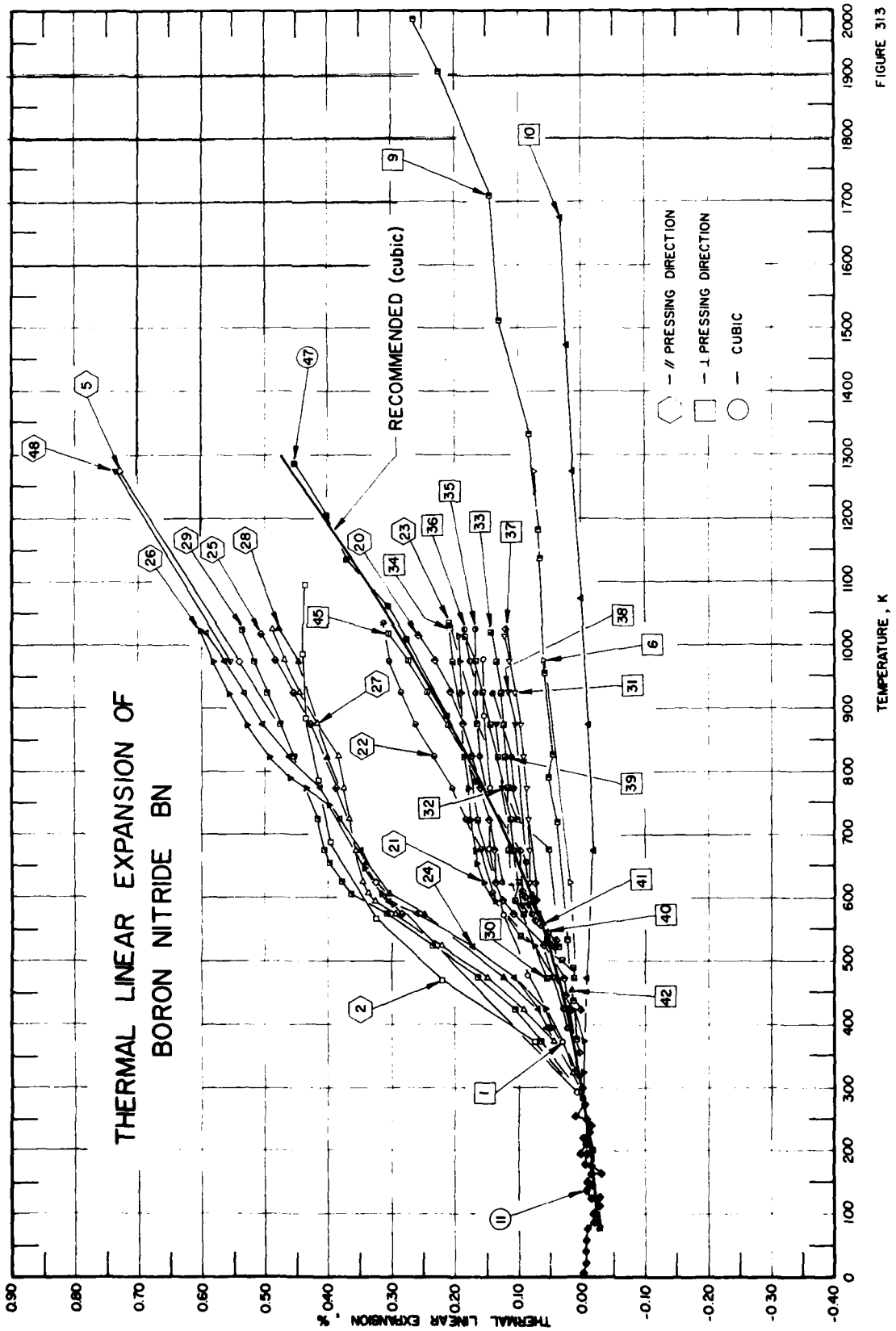

THERMAL LINEAR EXPANSION OF
BORON NITRIDE BN
RECOMMENDED (cubic)
// PRESSING DIRECTION
⊥ PRESSING DIRECTION
CUBIC
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 313

SPECIFICATION TABLE 313. THERMAL LINEAR EXPANSION OF BORON NITRIDE BN

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	822	Kuznetsova, I.G. and Poluboyarinov, D.N.	1967		293-978	1	98.8+ B and N; impurities < 1.0 each Si, Al, Mg, Fe; specimen pressed at 300-400 kg/cm^2 at 1873-2073 K for up to 20 min; specific history of specimen tested unknown; expansion measured perpendicular to direction of max pressure.
2	822	Kuznetsova, I.G. and Poluboyarinov, D.N.	1967		293-1095	2	Similar to above specimen except expansion measured parallel to direction of max pressure.
3	3	Steele, S.R., Pappis, J., Schilling, H., and Hagan, L.	1967		273,1273		Specimen deposited from the vapor at 1673-2173 K.
4	434	Finlay, G.R.	1957		293,1073		56.0 N, 42.0 B; made from BCl_3 and cracked ammonia.
5	823	Taylor, K.M.	1955		298-1273		97.0 BN, 2.4 B_2O_3, 0.25 SiO_2, 0.15 Al_2O_3, 0.08 C; made by hot pressing powder in graphite dies at relatively high temperature under moderate pressure; apparent density 2.12 g/cc; expansion measured parallel to pressing direction.
6	823	Taylor, K.M.	1955		298-1273		The above specimen; expansion measured perpendicular to pressing direction.
7	824	Pease, R.S.	1952	X	283-1073		Commercially prepared boron nitride supplied by British Drug House, Ltd.; poorly crystalline; recrystallization achieved by heating the material at 2323 K for about 2 hr in a stream of nitrogen; traces of magnesium, carbon and silicon along with a variety of other metallic impurities amounting to less than 0.6%; specific gravity 2.29 ±0.03; expansion measured along the a-axis; lattice parameter reported at 283 K as 2.5042 Å; 2.5041 Å at 293 K determined by graphical interpolation.
8	824	Pease, R.S.	1952	X	283-1073		The above specimen; expansion measured along the c-axis; lattice parameter reported at 283 K as 6.654 Å; 6.657 Å at 293 K determined by graphical interpolation.
9	63	Pears, C.D. and Oglesby, S.	1962		283-2135		52.4 N, 42.9 B; Carborundum Co.; initial length 7.75 cm; final length 8.26 cm; elements found by semi-quantitative emission spectrography before exposure 0.2 Ca, 0.2 Ti, 0.1 Si; after exposure 55.0 N, 41.5 B, 0.13 C; hot pressed; specimen cracked and distorted on post inspection; Run 11E; density in g cm^{-3} at 298 K before exposure 2.14 by ASTM method B311-58, 2.15 by wax-coating specimen, 2.16 by immersion in xylene; after exposure 1.96 by ASTM method, 1.99 by wax-coating specimen, and 2.17 by immersion in xylene; measured in helium atm; reported error 5%.
10	72	Fulkerson, S.D.	1959	L	273-1673		No details given.
11	160	Schaake, H.F.	1969	X	4.2-298		Specimen from General Electric Corp., ground to <325 mesh; 10% Ir added for calibration, pressed into copper sample holder.
12	825	Steele, S.R.	1965		373-1348	BN-32	CVD process vapor deposited specimen, formed from BCl_3 and NH_3; specimen deposited on smooth graphite; expansion of isotropic specimen measured along a-axis.
13	825	Steele, S.R.	1965		373-1348	BN-32	The above specimen; expansion measured along c-axis.
14	825	Steele, S.R.	1965		373-1348	BN-8	Similar to the above specimen; expansion measured along a-axis.
15	825	Steele, S.R.	1965		373-1273	BN-8	The above specimen; expansion measured along c-axis.

SPECIFICATION TABLE 313. THERMAL LINEAR EXPANSION OF BORON NITRIDE BN (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
16	825	Steele, S.R.	1965		373-1348	BN-30	Similar to the above specimen; expansion measured along a-axis.
17	825	Steele, S.R.	1965		373-1348	BN-30	The above specimen; expansion measured along c-axis.
18	825	Steele, S.R.	1965		373-1348	BN-28	Similar to the above specimen except anisotropic; expansion measured along a-axis.
19	825	Steele, S.R.	1965		373-1348	BN-28	The above specimen; expansion measured along c-axis.
20	816	Gaal, P.S.	1969	L	447-1014	AR-1A	A single slug of Carborundum grade A, originally hot pressed to a 9 in. diameter x 8 in. long cylinder; measurements parallel to direction of pressing; specimen from top of the as-pressed slug; expansion measured with increasing temperature; zero-point correction is -0.008% at 293 K.
21	816	Gaal, P.S.	1969	L	1014-293	AR-1A	The above specimen; expansion measured with decreasing temperature; zero-point correction is -0.072% at 293 K.
22	816	Gaal, P.S.	1969	L	319-1033	AR-2B	Similar to the above specimen; measurements parallel to direction of pressing; specimen taken from the top of as-pressed slug; expansion measured with increasing temperature; zero-point correction is -0.006% at 293 K.
23	816	Gaal, P.S.	1969	L	1033-293	AR-2B	The above specimen; expansion measured with decreasing temperature.
24	816	Gaal, P.S.	1969	L	393-1019	AR-1A	Similar to the above specimen; expansion measured with increasing temperature; specimen taken from bottom of as-pressed slug; expansion measured in the direction parallel to pressing; zero-point correction is -0.016% at 293 K.
25	816	Gaal, P.S.	1969	L	1019-293	AR-1A	The above specimen; expansion measured with decreasing temperature in the direction parallel to pressing; zero-point correction is -0.014% at 293 K.
26	816	Gaal, P.S.	1969	L	394-1023	AR-1B	Similar to the above specimen; expansion measured with increasing temperature; specimen taken from bottom of as-pressed slug; expansion measured in the direction parallel to pressing; first run; zero-point correction is -0.018% at 293 K.
27	816	Gaal, P.S.	1969	L	1023-293	AR-1B	The above specimen; expansion measured with decreasing temperature; specimen taken from bottom of as-pressed slug in the direction parallel to pressing; first run; zero-point correction is -0.129% at 293 K.
28	816	Gaal, P.S.	1969	L	394-1023	AR-1B	The above specimen; second heating cycle; zero-point correction is -0.013% at 293 K.
29	816	Gaal, P.S.	1969	L	1023-293	AR-1B	The above specimen; second cooling cycle; zero-point correction is 0.045% at 293 K.
30	816	Gaal, P.S.	1969	L	471-1014	AR-4A	Similar to the above specimen; expansion measured with increasing temperature; specimen taken from top of the as-pressed slug; measurements normal to direction of pressing; zero-point correction is 0.040% at 293 K.
31	816	Gaal, P.S.	1969	L	1014-293	AR-4A	The above specimen; cooling cycle; measurement normal to direction of pressing; zero-point correction is -0.02% at 293 K.
32	816	Gaal, P.S.	1969	L	443-1020	AR-5A	Similar to the above specimen; expansion measured with increasing temperature; normal to direction of pressing; specimen taken from center of as-pressed slug; zero-point correction is -0.008% at 293 K.
33	816	Gaal, P.S.	1969	L	1020-293	AR-5A	The above specimen; cooling cycle; zero-point correction is -0.027% at 293 K.

SPECIFICATION TABLE 313. THERMAL LINEAR EXPANSION OF BORON NITRIDE BN (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
34	816	Gaal, P.S.	1969	L	440-1023	AR-3	Similar to the above specimen; expansion measured with increasing temperature normal to direction of pressing; specimen taken from the bottom of as-pressed slug.
35	816	Gaal, P.S.	1969	L	1023-293	AR-3	The above specimen; cooling cycle; zero-point correction is -0.041% at 293 K.
36	816	Gaal, P.S.	1969	L	392-1023	AR-4B	Similar to the above specimen; expansion measured with increasing temperature normal to the direction of pressing; specimen taken from top of as-pressed slug; first cycle; zero-point correction is 0.012% at 293 K.
37	816	Gaal, P.S.	1969	L	1023-293	AR-4B	The above specimen; first cooling cycle; zero-point correction is -0.05% at 293 K.
38	816	Gaal, P.S.	1969	L	388-1023	AR-4B	The above specimen; second heating cycle.
39	816	Gaal, P.S.	1969	L	1023-293	AR-4B	The above specimen; second cooling cycle; zero-point correction is 0.029% at 293 K.
40	816	Gaal, P.S.	1969	L	354-823	AR-4B	Similar to the above specimen; expansion measured with increasing temperature normal to direction of pressing; specimen taken from the center of as-pressed slug; first cycle; zero-point correction is -0.004% at 293 K.
41	816	Gaal, P.S.	1969	L	673-354	AR-5B	The above specimen; first cooling cycle; zero-point correction is -0.004% at 293 K.
42	816	Gaal, P.S.	1969	L	354-923	AR-5B	The above specimen; second heating cycle; zero-point correction is -0.004% at 293 K.
43*	816	Gaal, P.S.	1969	L	923-293	AR-5B	The above specimen; second cooling cycle; zero-point correction is -0.033% at 293 K.
44*	816	Gaal, P.S.	1969	L	390-1019	AR-5A	Specimen similar to one from curve 32; 336 hr in moisture chamber; expansion measured with increasing temperature normal to direction of pressing; zero-point correction is 0.118% at 293 K.
45	816	Gaal, P.S.	1969	L	1017-293	AR-5A	The above specimen; cooling cycle; zero-point correction is 0.081% at 293 K.
46	826	Novikova, N.A., Vlasov, E.G., and Nepomnyashchii, L.B.	1971		293-2032	Pyrolitic BN	57.85 N, 42.15 B; expansion measured along a-axis; density 2.13 gm/cm^3; porosity 1.4%.
47	818	Slack, G.A. and Bartram, S.F.	1974	X	0-1200		Cubic BN powder structure; particle size ~40 μm; lattice parameter reported at 300 K as 3.6155 Å; reported error ±15%.
48	817	Murata, Y. and Miccioli, B.R.	1970	L	298-1273		57.07 N, 42.94 O, nil B_2O_3; hexagonal structure; particle size 4.5 μm; dimensions rectangular bar 6.35 x 6.35 x 76.2 mm; heating rate 3 K/min; expansion measured parallel to pressed direction.
49*	817	Murata, Y. and Miccioli, B.R.	1970	L	298-1273		The above specimen except expansion measured normal to pressed direction.

* Not shown in figure.

DATA TABLE 313. THERMAL LINEAR EXPANSION OF BORON NITRIDE BN

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
293	0.000
371	0.030
479	0.086
574	0.124
677	0.146
775	0.144
388	0.154
978	0.154

CURVE 2

T	$\Delta L/L_0$
293	0.000*
371	0.074
469	0.220
567	0.324
687	0.396
784	0.416
882	0.435
984	0.440
1095	0.438

CURVE 3

T	$\Delta L/L_0$
273	-0.0082
1273	0.4018

CURVE 4

T	$\Delta L/L_0$
293	0.000
1073	0.228

CURVE 5

T	$\Delta L/L_0$
298	0.005
623	0.325
973	0.540
1273	0.730

CURVE 6

T	$\Delta L/L_0$
298	0.0003*
623	0.0190
973	0.0597
1273	0.0747

CURVE 7

T	$\Delta L/L_0$
283	0.004
303	-0.004
393	-0.028
493	-0.048
583	-0.068
683	-0.084
783	-0.096
878	-0.104
973	-0.108
1073	-0.108

CURVE 8

T	$\Delta L/L_0$
283	-0.045
303	0.045
393	0.421
493	0.841
583	1.232
683	1.622
783	2.013
873	2.389
882	2.449
973	2.869
1073	3.230

CURVE 9

T	$\Delta L/L_0$
283	-0.001
377	0.009
438	0.012
533	0.022
720	0.039
790	0.051
826	0.047
955	0.058
1138	0.066
1181	0.069
1331	0.081
1512	0.103
1709	0.146
1905	0.226
1989	0.265
2026	0.297*
2051	0.339*
2115	0.408*
2135	0.566*

CURVE 9 (cont.)

T	$\Delta L/L_0$
2135	0.658*
2135	0.733*

CURVE 10

T	$\Delta L/L_0$
273	0.000*
473	-0.009
673	-0.019
873	-0.010
1073	0.000
1273	0.013
1473	0.023
1673	0.034

CURVE 11

T	$\Delta L/L_0$
4.2	-0.0025
4.2	-0.0019*
22	-0.0083
40	-0.0061
58	-0.0064
77.4	-0.0100
77.4	-0.0166*
88	-0.0199
100	-0.0196
104	-0.0144*
112	-0.0207
125	-0.0166
128	-0.0271
138	-0.0207*
138	-0.0072
145	-0.0169
150	-0.0086
150	-0.0158*
162	-0.0301
162	-0.0138
175	-0.0163
177	-0.0053
194.5	-0.0080
194.5	0.0003
194.5	-0.0077*
210	-0.0075
210	-0.0141*
220	-0.0014
225	-0.0089*
230	-0.0122

CURVE 11 (cont.)

T	$\Delta L/L_0$
240	-0.0130
250	-0.0097
255	0.0100
260	-0.0069*
273	-0.0061
273	0.0033*
296	0.0017*
298	-0.0011

CURVE 12

T	$\Delta L/L_0$
373	0.013
473	0.041
573	0.128
673	0.215
773	0.198
873	0.327
973	0.348
1073	0.376
1173	0.406
1273	0.411
1348	0.422

CURVE 13

T	$\Delta L/L_0$
373	0.005
473	0.010
573	0.016
673	0.123
773	0.170
873	0.236
973	0.283
1073	0.329
1173	0.376
1273	0.422
1348	0.447

CURVE 14

T	$\Delta L/L_0$
373	0.014
473	0.046
573	0.090
673	0.142

CURVE 14 (cont.)

T	$\Delta L/L_0$
773	0.195
873	0.230
973	0.267
1073	0.297
1173	0.327
1273	0.353
1348	0.362

CURVE 15

T	$\Delta L/L_0$
373	0.005
473	0.010
573	0.016
673	0.039
773	0.081
873	0.124
973	0.167
1073	0.227
1173	0.304
1273	0.337

CURVE 16

T	$\Delta L/L_0$
373	0.135
473	0.047
573	0.091
673	0.140
773	0.185
873	0.234
973	0.280
1073	0.325
1173	0.371
1273	0.407
1348	0.444

CURVE 17

T	$\Delta L/L_0$
373	0.026
473	0.051
573	0.078
673	0.124
773	0.174
873	0.220

CURVE 17 (cont.)

T	$\Delta L/L_0$
973	0.264
1073	0.310
1173	0.358
1273	0.404*
1348	0.428*

CURVE 18

T	$\Delta L/L_0$
373	-0.0052
473	-0.0061
573	0.0037
673	0.0156
773	0.0275
873	0.4980
973	0.0706
1073	0.0931
1173	0.1136
1273	0.1341
1348	0.1487

CURVE 19

T	$\Delta L/L_0$
373	0.097
473	0.304
573	0.563
673	0.795
773	1.015
873	1.235
973	1.456
1073	1.663
1173	1.888
1273	2.040
1348	2.145

CURVE 20

T	$\Delta L/L_0$
447	0.024
473	0.028
523	0.060
578	0.107
596	0.123
623	0.135
673	0.139
723	0.145

* Not shown in figure.

DATA TABLE 313. THERMAL LINEAR EXPANSION OF BORON NITRIDE BN (continued)

T	$\Delta L/L_0$
CURVE 20 (cont.)	
773	0.159
823	0.172
873	0.188
923	0.206
973	0.230
1014	0.256
CURVE 21	
1014	0.192
973	0.191
923	0.189
873	0.187*
823	0.183
773	0.179
723	0.173
673	0.168
653	0.164
623	0.152
593	0.134
573	0.113*
523	0.072
473	0.037*
423	0.013
373	-0.005
323	-0.005
300	0.000*
293	0.000*
CURVE 22	
319	0.003
373	0.010*
423	0.014*
473	0.031*
523	0.065*
573	0.117*
593	0.131*
609	0.140
623	0.144*
673	0.159
723	0.181
773	0.204
823	0.232
873	0.262
923	0.284
973	0.302
1033	0.314

T	$\Delta L/L_0$
CURVE 23	
1033	0.209
973	0.201
923	0.193*
873	0.182*
823	0.175*
773	0.171*
723	0.165
673	0.160*
623	0.153*
573	0.126*
540	0.096
523	0.068*
501	0.030
490	0.013
473	0.011
423	0.006*
373	0.002*
323	0.002*
304	0.000*
293	0.000*
CURVE 24	
393	0.053
423	0.069
473	0.107
523	0.171
573	0.262
595	0.303
623	0.322*
673	0.349
723	0.381
773	0.414
823	0.464
873	0.503
923	0.533
973	0.565
1019	0.593
CURVE 25	
1019	0.505
973	0.481
923	0.453
873	0.428
823	0.407*
773	0.388
723	0.374*

T	$\Delta L/L_0$
CURVE 25 (cont.)	
673	0.362*
623	0.344*
592	0.324*
573	0.283
523	0.213*
473	0.149*
423	0.095*
373	0.047*
323	0.015*
296	0.004*
293	0.000*
CURVE 26	
394	0.045
423	0.058
473	0.106*
523	0.172*
573	0.261*
590	0.296
606	0.314
623	0.326*
649	0.341
673	0.348*
723	0.377*
748	0.398
773	0.433
790	0.461
823	0.492
873	0.528
923	0.554
973	0.580
1023	0.600
CURVE 27	
1023	0.489
973	0.469
923	0.443
873	0.417
823	0.381
773	0.376
723	0.367
673	0.355
623	0.348
606	0.336
594	0.325
573	0.292

T	$\Delta L/L_0$
CURVE 27 (cont.)	
523	0.220
473	0.149
423	0.090
373	0.043
323	0.013
299	0.004*
293	0.000*
CURVE 28	
394	0.056*
423	0.072*
473	0.122
523	0.178*
573	0.249
606	0.305
623	0.321*
652	0.340
673	0.348*
723	0.360*
773	0.378*
823	0.399
873	0.419*
923	0.439*
973	0.459
1023	0.479
CURVE 29	
1023	0.537
973	0.517
923	0.497
873	0.477
823	0.457
773	0.436*
723	0.418
673	0.406
652	0.398
623	0.379
606	0.363
573	0.307
523	0.236
473	0.162
423	0.106
373	0.056
323	0.019*
299	0.004*
293	0.000*

T	$\Delta L/L_0$
CURVE 30	
471	0.055
523	0.071*
573	0.091
595	0.102
623	0.099
673	0.104
723	0.111
773	0.119
823	0.131
873	0.143
923	0.155
973	0.168
1014	0.181
CURVE 31	
1014	0.121
973	0.113
923	0.106
873	0.098
823	0.091
773	0.088
723	0.084
673	0.082
623	0.082
597	0.082
573	0.070
523	0.047*
473	0.027*
423	0.017*
373	0.009*
323	0.003*
299	0.000*
293	0.000*
CURVE 32	
443	0.025*
473	0.030*
523	0.045
573	0.078*
589	0.095
623	0.099*
673	0.108*
723	0.117*
773	0.126
823	0.137*
873	0.135

T	$\Delta L/L_0$
CURVE 32 (cont.)	
923	0.156*
973	0.161*
1020	0.177*
CURVE 33	
1020	0.142
973	0.134
923	0.127
873	0.123
823	0.121
773	0.118*
723	0.116
673	0.113
623	0.111
597	0.111*
573	0.089*
523	0.053*
473	0.026*
423	0.011*
373	0.002*
323	0.000*
299	0.000*
293	0.000*
CURVE 34	
440	0.013*
473	0.019*
523	0.039
573	0.076*
590	0.088*
623	0.088*
673	0.051
723	0.101
773	0.118*
823	0.137*
873	0.166
923	0.189*
973	0.199*
1023	0.207
CURVE 35	
1023	0.167
973	0.170*
923	0.167
873	0.164*

* Not shown in figure.

DATA TABLE 313. THERMAL LINEAR EXPANSION OF BORON NITRIDE BN (continued)

T	$\Delta L/L_0$
CURVE 35 (cont.)	
823	0.161
773	0.157*
723	0.151*
673	0.141*
623	0.126
573	0.100*
523	0.066*
473	0.036*
423	0.009*
373	-0.001*
323	-0.002*
298	0.000*
293	0.000*
CURVE 36	
392	0.022
423	0.029
473	0.043
523	0.060*
573	0.078
623	0.088*
656	0.085
673	0.087*
723	0.095*
773	0.110*
823	0.125*
873	0.146*
923	0.160*
973	0.174
1023	0.182
CURVE 37	
1023	0.120
973	0.112*
923	0.107*
873	0.100*
823	0.093*
773	0.090*
723	0.085*
673	0.080*
623	0.075
596	0.073
573	0.066*
523	0.041*
473	0.018*
423	0.001

T	$\Delta L/L_0$
CURVE 37 (cont.)	
373	-0.008*
323	-0.008*
299	-0.003*
293	0.000*
CURVE 38	
388	0.024*
423	0.024*
473	0.035
523	0.053*
573	0.077*
589	0.086
623	0.085*
673	0.085*
723	0.085*
773	0.090*
823	0.096*
873	0.104
923	0.116
973	0.139*
1023	0.170*
CURVE 39	
1023	0.199*
973	0.160*
923	0.138
873	0.122*
823	0.113
773	0.108
723	0.108*
673	0.108*
623	0.108*
592	0.107*
573	0.088*
523	0.055*
473	0.029*
423	0.022
373	0.013*
323	0.006*
299	0.004*
293	0.000*
CURVE 40	
354	0.003
373	0.004*

T	$\Delta L/L_0$
CURVE 40 (cont.)	
423	0.008*
473	0.015*
503	0.024*
523	0.033*
532	0.040
544	0.055
565	0.074
573	0.080*
584	0.085*
601	0.092
610	0.095
623	0.095*
673	0.096
723	0.100*
773	0.104*
823	0.111*
CURVE 41	
673	0.084*
650	0.083*
623	0.080*
603	0.077
590	0.074*
574	0.068*
560	0.062
550	0.056*
541	0.049*
532	0.040*
523	0.033*
503	0.024*
473	0.015*
423	0.008*
373	0.004*
354	0.003*
CURVE 42	
354	0.003*
373	0.004*
423	0.010*
452	0.015
473	0.022*
501	0.032*
523	0.043*
543	0.055*
573	0.077*
585	0.086*

T	$\Delta L/L_0$
CURVE 42 (cont.)	
603	0.091*
616	0.094*
623	0.095*
673	0.096*
723	0.097*
773	0.106*
823	0.118*
873	0.133*
923	0.152*
CURVE 43*	
923	0.123
873	0.116
823	0.110
773	0.106
723	0.104
673	0.103
623	0.103
612	0.100
605	0.098
573	0.081
523	0.056
473	0.024
423	0.003
418	0.001
373	0.000
323	0.000
299	0.000
293	0.000
CURVE 44*	
390	0.088
423	0.118
473	0.099
513	0.097
523	0.104
573	0.144
581	0.151
623	0.153
673	0.163
707	0.182
720	0.200
723	0.209
729	0.227
733	0.260
736	0.555

T	$\Delta L/L_0$
CURVE 44 (cont.)*	
735	0.779
740	0.799
767	0.467
773	0.406
779	0.378
794	0.361
812	0.346
823	0.339
873	0.326
923	0.320
973	0.328
1019	0.345
CURVE 45	
1017	0.303
973	0.272
923	0.242
873	0.210
823	0.189*
773	0.172*
723	0.161*
673	0.156*
623	0.151*
599	0.139*
573	0.109*
523	0.067*
473	0.037*
423	0.013*
373	0.008*
323	0.004*
299	0.002*
293	0.000*
CURVE 46‡	
293	0.000
407	0.006
529	0.015
590	0.021
715	0.034*
781	0.042
1278	0.129
1531	0.189
1779	0.258
2032	0.341*

T	$\Delta L/L_0$
CURVE 47‡	
0	-0.013
200	-0.008
300	0.001*
400	0.015
500	0.037*
600	0.065
800	0.145
1000	0.251
1200	0.375
CURVE 48	
298	0.004*
973	0.551
1273	0.735
CURVE 49*	
298	0.000
973	0.061
1273	0.075

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

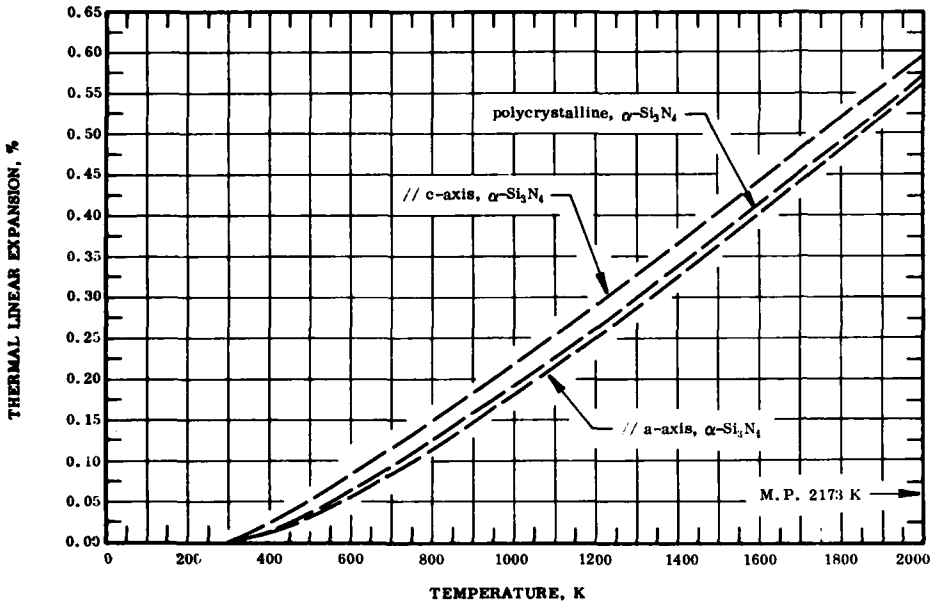
DATA TABLE 313. COEFFICIENT OF THERMAL LINEAR EXPANSION OF BORON NITRIDE BN

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 46 *,‡	
293	0.46
407	0.60
529	0.89
590	0.93
715	1.14
781	1.40
1278	2.12
1531	2.55
1779	3.09
2082	3.41
CURVE 47 *,‡	
0	0.00
200	0.50
300	1.15
400	1.80
500	2.50
600	3.23
800	4.70
1000	5.96
1200	6.45

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 314R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF SILICON NITRIDE Si_3N_4



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	0.8
300	0.0002	0.0007	0.0004	0.8
400	0.011	0.021	0.014	1.8
500	0.029	0.051	0.036	2.4
600	0.055	0.081	0.064	2.8
700	0.084	0.112	0.093	3.1
800	0.114	0.145	0.124	3.2
900	0.146	0.180	0.157	3.4
1000	0.179	0.216	0.191	3.5
1100	0.213	0.252	0.226	3.6
1200	0.249	0.290	0.263	3.6
1300	0.285	0.328	0.299	3.7
1400	0.323	0.366	0.337	3.8
1500	0.361	0.405	0.376	3.9
1600	0.400	0.444	0.415	3.9
1700	0.439	0.482	0.453	4.0
1800	0.479	0.521	0.493	4.0
1900	0.520	0.558	0.533	4.0
2000	0.561	0.595	0.572	4.1

REMARKS

The provisional values are based on the measurements for polycrystalline α-Si_3N_4 (curves 3 to 7, and 10 to 12) and are considered accurate to within ± 10% at temperatures below 1300 K and ± 15% above 1300 K. The provisional values for the axial thermal linear expansion are based on the above values and on the trends of the data reported in curves 15-22 and 24-27. These provisional values are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = 4.965 \times 10^{-2} - 4.387 \times 10^{-4} T + 1.088 \times 10^{-6} T^2 - 5.847 \times 10^{-10} T^3$ (293-500 K)

$\Delta L/L_0 = -7.956 \times 10^{-2} + 1.621 \times 10^{-4} T + 1.139 \times 10^{-7} T^2 - 1.749 \times 10^{-11} T^3$ (500-2000 K)

// c-axis: $\Delta L/L_0 = -4.706 \times 10^{-3} - 1.082 \times 10^{-4} T + 3.922 \times 10^{-7} T^2 + 9.473 \times 10^{-11} T^3$ (293-500 K)

$\Delta L/L_0 = -6.583 \times 10^{-2} + 1.689 \times 10^{-4} T + 1.443 \times 10^{-7} T^2 - 3.172 \times 10^{-11} T^3$ (500-2000 K)

polycrystalline: $\Delta L/L_0 = 3.366 \times 10^{-2} - 3.435 \times 10^{-4} T + 8.941 \times 10^{-7} T^2 - 3.939 \times 10^{-10} T^3$ (293-500 K)

$\Delta L/L_0 = -7.643 \times 10^{-2} + 1.682 \times 10^{-4} T + 1.210 \times 10^{-7} T^2 - 2.147 \times 10^{-11} T^3$ (500-2000 K)

The values for the coefficient of thermal expansion are primarily derived by differentiating the above equations for polycrystalline sample and are considered accurate to about ± 15%.

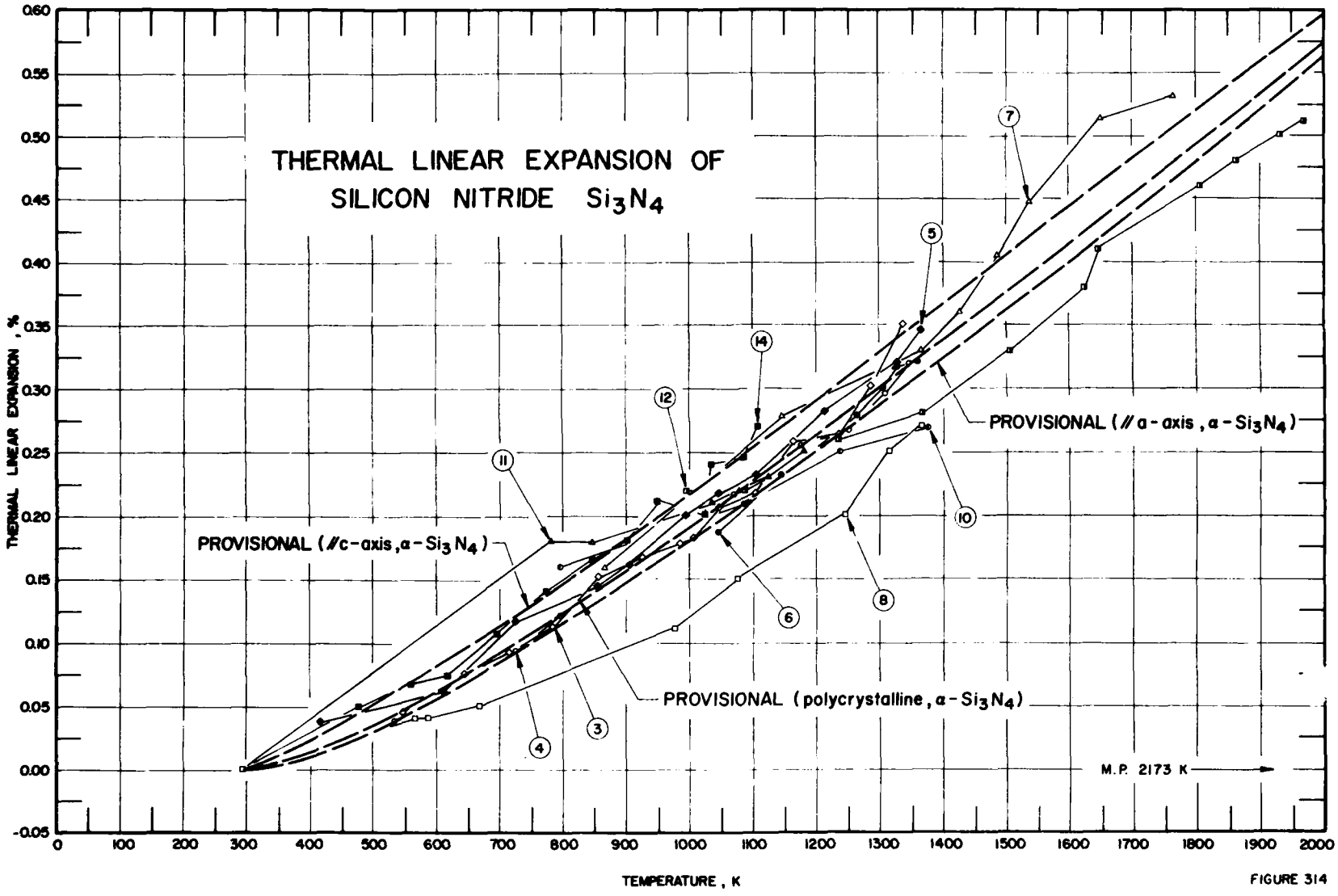

THERMAL LINEAR EXPANSION OF
SILICON NITRIDE Si_3N_4
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
PROVISIONAL (// c-axis, α-Si_3N_4)
PROVISIONAL (// a-axis, α-Si_3N_4)
PROVISIONAL (polycrystalline, α-Si_3N_4)
M.P. 2173 K
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
3
4
5
6
7
8
10
11
12
14

FIGURE 314

SPECIFICATION TABLE 314. THERMAL LINEAR EXPANSION OF SILICON NITRIDE Si_3N_4

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	844	Tokuyama, T., Fujii, Y., Sugita, Y., and Kishino, S.	1967	X	293-1273		Silicon nitride film deposited through chemical reaction of SiH_4 and NH_3 at 1073 K and 1273 K on surface of the silicon substrates (silicon substrates of the (111) surface cut along [110] direction to the dimension of 20 x 5 mm and oxidized in steam at 1073 K and 1273 K (respectively); thermal expansion coefficient of film determined using coefficient of substrates; expansion measured by bending film to deflect x-ray beam; authors state that the expansion of a nitride film is assumed temperature independent.
2*	3	Steele, S.R., Pappis, J., Schilling, H., and Hagan, L.	1967		273,1273		Specimen deposited from a vapor at 1423-1573 K.
3	845	Wells, W.M.	1964		521-1337		Specimen rectangular 10.16 x 1.27 x 1.27 cm; first run.
4	845	Wells, W.M.	1964		530-1345		The above specimen; data taken on second run.
5	845	Wells, W.M.	1964		419-1367		The above specimen; data taken on third run.
6	845	Wells, W.M.	1964		1048-1359		The above specimen; data taken on fourth run.
7	845	Wells, W.M.	1964		862-1763		Similar to the above specimen; data taken using less precise apparatus than the above data.
8	318	Neel, D.S., Pears, C.D., and Oglesby, S., Jr.	1962		294-1365		Calculated composition before exposure 60.08 Si, 39.91 N, Carborundum Co.; initial length 7.58 cm; elements found by semi-quantitative emission spectrography 0.7 Fe, 0.6 Ca, 0.3 Al, 0.1 Mn, Mg, Zr, Cr, and trace Ti, after exposure 0.49 C; formed by A casting; specimen broken on post inspection; Run SRI-E1; density in g cm^{-3} at 298 K before exposure 2.5 by ASTM method B311-58, 2.4 by wax-coating specimen, 2.8 by immersion in xylene, after exposure 2.8 by ASTM method, 2.5 by wax-coating specimen, and 2.9 by immersion in xylene; measured in helium atm; reported error 2%.
9*	318	Neel, D.S., et al.	1962		1365-796		Cooling of above specimen to 796 K.
10	318	Neel, D.S., et al.	1962		796-1374		Reheating of above specimen to 1374 K.
11	318	Neel, D.S., et al.	1962		1374-294		Recooling of above specimen to 294 K.
12*	318	Neel, D.S., et al.	1962		780-2077		Final heating of above specimen.
13*	318	Neel, D.S., et al.	1962		2077,294		Final cooling of above specimen; specimen found broken on post inspection.
14*	515	Burkhardt, P.J. and Marvel, R.F.	1969		293-1105		98.0 Si_3N_4 with impurities detected by electron microprobe Mo, Cl, O, Ca, Al; sample film prepared by sputtering 1-2 μ thick onto strip of annealed molybdenum metal of 1.27 cm wide, 7.67 cm long, 0.00762 cm thick, and then rolled over edge to provide lateral curvature; cathetometer used to measure distance between two reference marks as function of temperature on freely suspended strip of film.
15*	846	Thompson, D.S. and Pratt, P.L.	1965	X	293-1659	β-Si_3N_4	Crystal structure; expansion measured along a-axis; lattice parameter reported at 293 K as 7.5966 Å; reported error ±0.1%.
16*	846	Thompson, D.S. and Pratt, P.L.	1965	X	293-1661	β-Si_3N_4	The above specimen; expansion measured along c-axis; lattice parameter re-
17*	846	Thompson, D.S. and Pratt, P.L.	1965	X	293-1680	α-Si_3N_4	Expansion measured on a-axis; L/6 5% Si; lattice parameter reported at 293 K as 7.7498 Å; reported error ±0.1%.
18*	846	Thompson, D.S. and Pratt, P.L.	1965	X	293-1673	α-Si_3N_4	The above specimen; expansion measured on c-axis; lattice parameter reported at 293 K as 5.6003 Å.

* Not shown in figure.

SPECIFICATION TABLE 314. THERMAL LINEAR EXPANSION OF SILICON NITRIDE Si_3N_4 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
19*	846	Thompson, D.S. and Pratt, P.L.	1965	X	293-1715	α-Si_3N_4	Similar to the above specimen; expansion measured on a-axis; L/3 1% Si; lattice parameter reported at 293 K as 7.7498 Å.
20*	846	Thompson, D.S. and Pratt, P.L.	1965	X	293-1692	α-Si_3N_4	The above specimen; expansion measured on c-axis; lattice parameter reported at 293 K as 5.5954 Å.
21*	846	Thompson, D.S. and Pratt, P.L.	1965	X	293-1681	α-Si_3N_4	Similar to the above specimen; L/8 3% Si; expansion measured on a-axis; lattice parameter reported at 293 K as 7.7533 Å.
22*	846	Thompson, D.S. and Pratt, P.L.	1965	X	293-1673	α-Si_3N_4	The above specimen; expansion measured on c-axis; lattice parameter reported at 293 K as 5.6043 Å.
23*	847	Gregor, L.V.	1968	T	293-1173		Film specimen obtained by sputtering particles onto surface and stripping film off; specimen 7.62 cm x 1.27 cm x 1.5 μ thick; film suspended vertically for measurement.
24*	848	Iwai, S. and Yasunaga, A.	1959	X	273-1673	α-Si_3N_4	Specimen prepared by heating pure Si and nitrogen at 1673 K; expansion measured along a-axis; lattice parameter reported at 293 K is 7.7500 Å; expansion along this axis does not seem reasonable.
25*	848	Iwai, S. and Yasunaga, A.	1959	X	273-1673	α-Si_3N_4	The above specimen; expansion measured along c-axis; lattice parameter reported at 293 K is 5.6146 Å.
26*	848	Iwai, S. and Yasunaga, A.	1959	X	273-1673	β-Si_3N_4	Specimen prepared by heating pure Si and nitrogen at 1673 K; expansion measured along a-axis; lattice parameter reported at 293 K is 7.6048 Å.
27*	848	Iwai, S. and Yasunaga, A.	1959	X	273-1673	β-Si_3N_4	The above specimen; expansion measured along c-axis; lattice parameter reported at 293 K is 2.9042 Å.
28*	849	Carr, E.M. and Bartlett, R.W.	1968		293, 1273		Duplex silicon nitride; three 1.875 O.D. ring specimen; 2.55, 2.54, and 2.51 g cm^{-3} densities which were cut from an isostatically pressed cylinder and were fired for 20 hr at 1523 K, then 8 hr at 1723 K before the measurements of change in diameter; during test each specimen underwent two complete thermal cycles between 293 and 1273 K.
29*	850	McLean, A.F., Fisher, E.A., and Bratton, R.J.	1973	L	293-1714	B2, 1:A9	Hot pressed specimen; expansion for sample 2, billet 1 in the direction parallel to hot press direction is same as for sample 9 in the direction perpendicular to hot press direction.
30*	850	McLean, A.F., et al.	1973	L	293-1716	A10	Similar to the above specimen; expansion for sample 10 in the direction perpendicular to hot press direction.
31*	850	McLean, A.F., et al.	1973	L	293-1714	B10	The above specimen; expansion in the direction parallel to hot press direction.
32*	850	McLean, A.F., et al.	1973	L	293-1720	B9	Similar to the above specimen; expansion for sample 9 in the direction parallel to hot press direction.
33*	850	McLean, A.F., et al.	1973	L	293-1705	A2,1	Similar to the above specimen; expansion for sample 2, billet 1 in the direction perpendicular to hot press direction.

DATA TABLE 314. THERMAL LINEAR EXPANSION OF SILICON NITRIDE Si_3N_4

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
293	0.000
1073	0.300
1273	0.377

CURVE 2*

T	$\Delta L/L_0$
273	-0.012
1273	0.588

CURVE 3

T	$\Delta L/L_0$
521	0.046
642	0.075
711	0.092
780	0.112
857	0.152
869	0.157
926	0.168
984	0.178
1009	0.183
1048	0.207
1101	0.217
1161	0.258
1234	0.263
1289	0.301
1337	0.350

CURVE 4

T	$\Delta L/L_0$
530	0.039
724	0.093
795	0.122
993	0.192
1070	0.218
1113	0.224
1173	0.255
1217	0.262
1250	0.267
1309	0.296
1345	0.320

CURVE 5

T	$\Delta L/L_0$
419	0.038
605	0.061
729	0.117

CURVE 5 (cont.)

T	$\Delta L/L_0$
854	0.145
903	0.161
993	0.200
1049	0.218
1103	0.233
1212	0.282
1329	0.321
1367	0.347

CURVE 6

T	$\Delta L/L_0$
1048	0.187
1143	0.233
1262	0.278
1302	0.299
1327	0.317
1359	0.321

CURVE 7

T	$\Delta L/L_0$
862	0.158
1144	0.279
1366	0.331
1423	0.360
1480	0.405
1536	0.447
1649	0.513
1763	0.536

CURVE 8

T	$\Delta L/L_0$
294	0.00
567	0.04
585	0.04
668	0.05
978	0.11
1075	0.15
1242	0.20
1362	0.25
1365	0.27

CURVE 9*

T	$\Delta L/L_0$
1365	0.27
796	0.16

CURVE 10

T	$\Delta L/L_0$
796	0.16
1087	0.21
1235	0.25
1374	0.27

CURVE 11

T	$\Delta L/L_0$
1374	0.27
1180	0.25
1121	0.23
1074	0.22
1033	0.21
845	0.18
831	0.18
780	0.18
294	0.00*

CURVE 12*

T	$\Delta L/L_0$
780	0.18
997	0.22
1088	0.23
1232	0.26
1363	0.28
1503	0.33
1624	0.38
1648	0.41
1807	0.46
1862	0.48
1933	0.50
1977	0.51
2077	0.53

CURVE 13*

T	$\Delta L/L_0$
2077	0.53
294	0.20

CURVE 14*

T	$\Delta L/L_0$
293	0.0000
312	0.0044
333	0.0079
346	0.0079
358	0.0091
360	0.0130

CURVE 14 (cont.)*

T	$\Delta L/L_0$
366	0.0079
379	0.0055
393	0.0104
403	0.0126
425	0.0152
438	0.0241
446	0.0229
456	0.0302
477	0.0503
502	0.0430
516	0.0543
560	0.0673
562	0.0622
590	0.0843
617	0.0742
651	0.0832
691	0.1064
726	0.0996
738	0.1117
772	0.1404
846	0.1647
877	0.1795
900	0.1795
926	0.1856
950	0.2112
1025	0.2013
1031	0.2404
1056	0.2481
1082	0.2446
1105	0.2697

CURVE 15*

T	$\Delta L/L_0$
293	0.000
414	-0.021
527	0.087
640	0.194
716	0.105
792	0.264
865	0.108
942	0.212
1005	0.276
1032	0.324
1063	0.367
1097	0.343
1150	0.324

CURVE 15 (cont.)*

T	$\Delta L/L_0$
1243	0.355
1326	0.467
1396	0.469
1484	0.370
1541	0.395
1614	0.516
1659	0.595

CURVE 16*

T	$\Delta L/L_0$
293	0.000
297	-0.007
406	-0.127
533	-0.062
635	0.106
712	0.138
790	0.172
862	0.106
935	0.216
1007	0.206
1035	0.199
1066	0.258
1103	0.278
1157	0.289
1250	0.316
1324	0.316
1401	0.351
1547	0.378
1621	0.468
1661	0.526

CURVE 17*

T	$\Delta L/L_0$
293	0.000
313	0.046
325	0.126
459	0.089
511	0.054
591	0.134
794	0.351
900	0.656
994	0.817
1087	1.668
1185	-0.072
1286	0.021
1361	0.039

CURVE 17 (cont.)*

T	$\Delta L/L_0$
1422	-0.032
1478	0.031
1566	0.115
1680	0.288

CURVE 18*

T	$\Delta L/L_0$
293	0.000
298	0.030
309	-0.025
325	0.314
466	0.146
518	0.336
593	0.170
732	0.021
793	0.489
891	0.780
999	1.127
1090	1.525
1179	0.241
1278	0.143
1354	0.143
1422	0.000
1471	0.011
1561	-0.154
1673	0.341

CURVE 19*

T	$\Delta L/L_0$
293	0.000
630	0.134
753	0.209
954	0.232
1041	0.529
1098	0.495
1148	0.501
1380	0.143
1451	0.015
1546	0.276
1624	0.293
1715	0.268

CURVE 20*

T	$\Delta L/L_0$
293	0.000
300	0.000

* Not shown in figure.

DATA TABLE 314. THERMAL LINEAR EXPANSION OF SILICON NITRIDE Si_3N_4 (continued)

T	$\Delta L/L_0$
CURVE 20 (cont.)*	
750	0.109
1041	0.481
1096	0.502
1121	0.550
1382	0.320
1454	0.061
1536	0.267
1623	0.668
1692	0.983
CURVE 21*	
293	0.000
570	0.030
771	0.080
909	0.045
1039	0.239
1094	0.304
1114	0.237
1136	0.312
1152	0.353
1184	0.297
1263	0.289
1374	0.337
1510	0.401
1564	0.355
1681	0.400
CURVE 22*	
293	0.000
298	0.000
577	-0.037
771	0.093
902	0.207
1021	0.136
1092	0.216
1111	0.284
1141	0.232
1149	0.298
1176	0.134
1261	0.230
1373	0.252
1511	0.412
1556	0.341
1673	0.564

T	$\Delta L/L_0$
CURVE 23*	
293	0.000
336	0.004
373	0.010
423	0.020
473	0.033
523	0.048
573	0.064
623	0.081
673	0.099
723	0.117
773	0.135
823	0.154
873	0.173
923	0.193
973	0.212
1023	0.232
1073	0.252
1123	0.272
1173	0.292
CURVE 24*	
273	0.000
293	0.000
473	0.003
673	0.004
873	0.008
1073	0.013
1273	0.022
1473	0.032
1673	0.044
CURVE 25*	
273	-0.009
293	0.000
473	0.009
673	0.043
873	0.085
1073	0.142
1273	0.232
1473	0.321
1673	0.443
CURVE 26*	
273	-0.003
293	0.000

T	$\Delta L/L_0$
CURVE 26 (cont.)*	
473	0.013
673	0.054
873	0.101
1073	0.162
1273	0.235
1473	0.327
1673	0.412
CURVE 27*	
273	0.000
293	0.000
473	0.014
673	0.055
873	0.103
1073	0.200
1273	0.300
1473	0.451
1673	0.654
CURVE 28*	
293	0.000
1273	0.441
CURVE 29*	
293	0.000
373	0.017
473	0.040
573	0.064
673	0.091
773	0.118
873	0.149
973	0.182
1073	0.214
1173	0.247
1273	0.282
1373	0.324
1473	0.368
1573	0.412
1673	0.460
1714	0.481
CURVE 30*	
293	0.000
373	0.014

T	$\Delta L/L_0$
CURVE 30 (cont.)*	
473	0.028
573	0.050
673	0.075
773	0.103
873	0.131
973	0.162
1073	0.194
1173	0.229
1273	0.267
1373	0.308
1473	0.350
1573	0.395
1673	0.441
1716	0.464
CURVE 31*	
293	0.000
373	0.014
473	0.033
573	0.058
673	0.085
773	0.111
873	0.139
973	0.171
1073	0.203
1173	0.240
1273	0.275
1373	0.316
1473	0.360
1573	0.404
1673	0.451
1714	0.472
CURVE 32*	
293	0.000
373	0.011
473	0.027
573	0.045
673	0.068
773	0.093
873	0.120
973	0.150
1073	0.182
1173	0.214
1273	0.250
1373	0.292

T	$\Delta L/L_0$
CURVE 32 (cont.)*	
1473	0.336
1573	0.383
1673	0.433
1720	0.457
CURVE 33*	
293	0.000
373	0.015
473	0.034
573	0.058
673	0.085
773	0.114
873	0.145
973	0.178
1073	0.212
1173	0.250
1273	0.289
1373	0.331
1473	0.376
1573	0.425
1673	0.476
1705	0.494

* Not shown in figure.

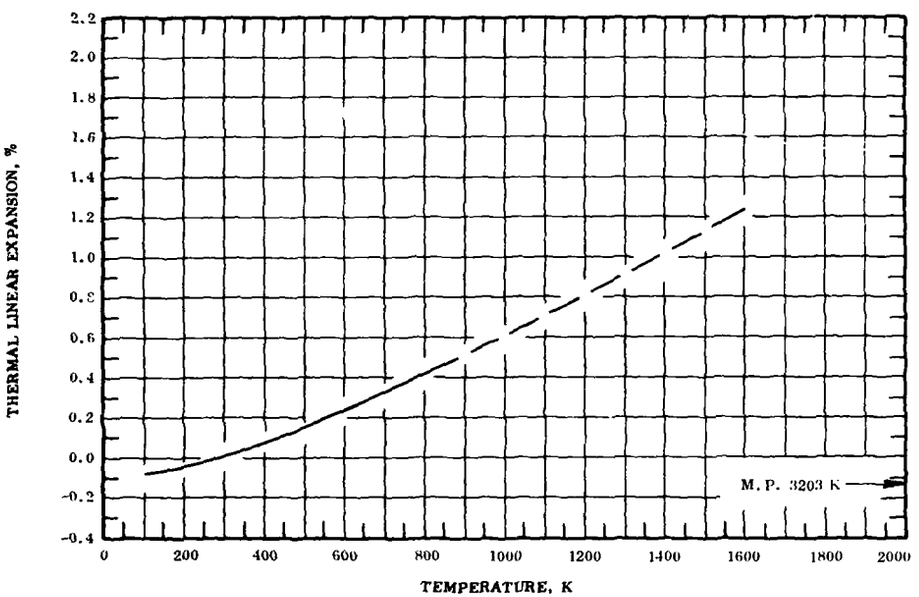
DATA TABLE 314. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SILICON NITRIDE Si_3N_4

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 23*	
293	0.76
336	1.31
373	1.80
423	2.32
473	2.78
523	3.10
573	3.30
623	3.46
673	3.58
723	3.66
773	3.75
823	3.81
873	3.86
923	3.90
973	3.93
1023	3.97
1073	3.98
1123	4.00
1173	4.00

* Not shown in figure.

FIGURE AND TABLE NO. 315R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF TITANIUM NITRIDE TiN



RECOMMENDED VALUES

{Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}}

T	$\Delta L/L_0$	α
100	-0.084	2.5
150	-0.063	3.7
200	-0.042	4.8
250	-0.019	5.6
293	0.000	6.3
300	0.005	6.4
400	0.078	7.4
500	0.156	8.1
600	0.240	8.6
700	0.328	9.0
800	0.420	9.4
900	0.515	9.7
1000	0.614†	10.0
1200	0.818†	10.3
1400	1.027†	10.5
1600	1.238†	10.6

† Provisional values.

REMARKS

The recommended values are considered accurate to within ± 5% at temperatures below 900 K and ± 10% above 900 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.175 + 4.911 \times 10^{-4}\, T + 3.848 \times 10^{-7}\, T^2 - 8.742 \times 10^{-11}\, T^3 \qquad (293\text{-}1600\ K)$$

The tabulated values for the coefficient of thermal expansion are derived primarily by differentiating the above equation and are considered accurate to about ± 10%.

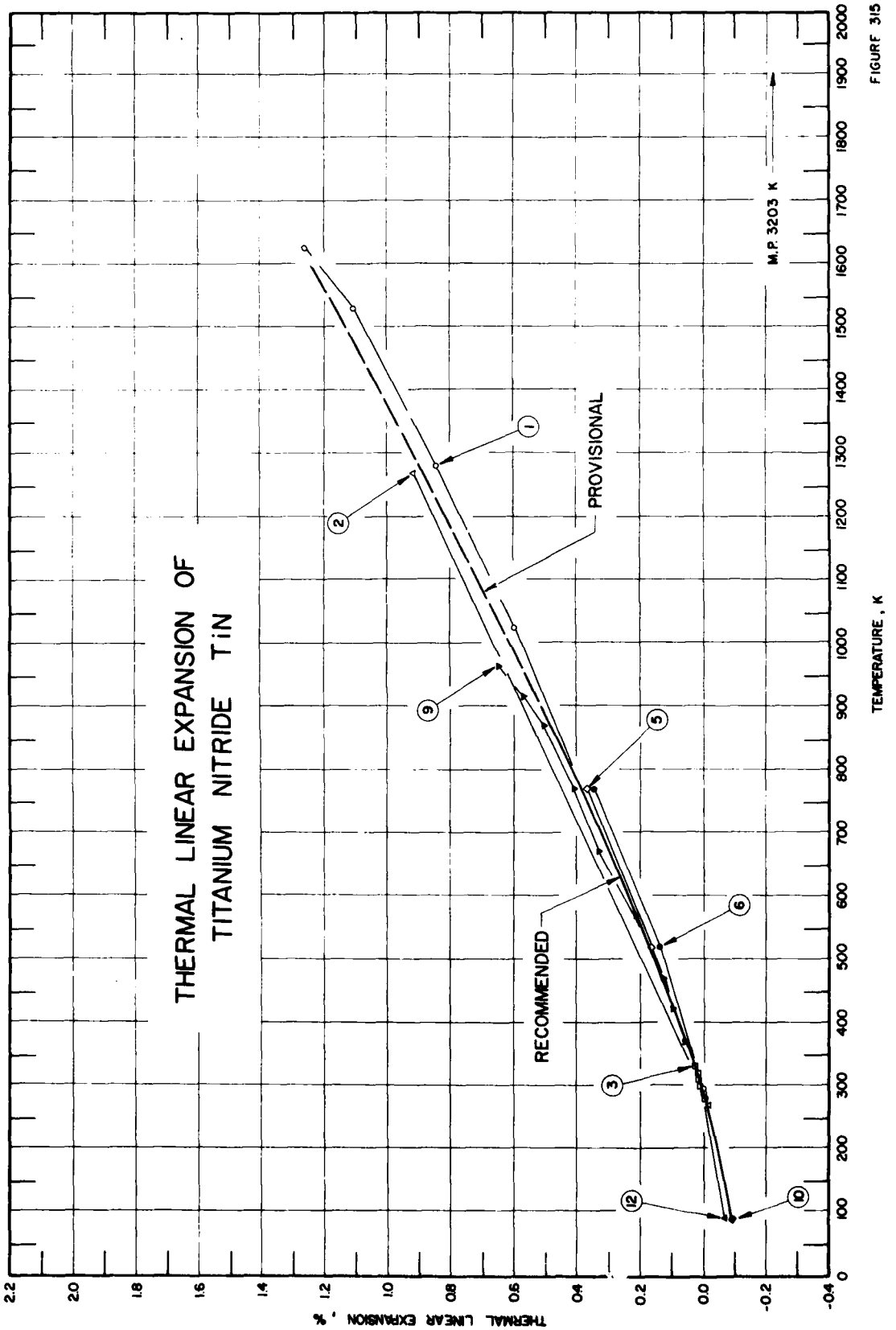

THERMAL LINEAR EXPANSION OF
TITANIUM NITRIDE TiN
PROVISIONAL
RECOMMENDED
M.P. 3203 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
5
6
9
10
12

FIGURE 315

SPECIFICATION TABLE 315. THERMAL LINEAR EXPANSION OF TITANIUM NITRIDE TiN

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	420	Houska, C.R.	1963	X	298-1629	$TiN_{0.95}$	96.91 Ti, 21.40 N, 0.73 O, 0.12 C, 0.1 Al, 0.6 Si, 0.6 Zr, 0.3 Cr, 0.2 Fe, and 0.2 Ni; by pressing less than 325 mesh powders at 16 000 psi, heated in a flowing NH_3 atmosphere to 1623 K for 2 hr; data obtained from (420) and (422); CuKα radiation used.
2	3	Steele, S.R., Pappis, J., Schilling, H., and Hagan, L.	1967		273,1273		Specimen deposited from vapor at 1773 K.
3	851	Straumanis, M.E., Faunce, C.A., and James, W.J.	1967	X	283-333		Material obtained from Union Carbide Co.; powder tested as received; analysis revealed 10% excess of nitrogen; lattice parameter reported at 293.2 K as 4.239527 Å.
4*	851	Straumanis, M.E., et al.	1967	X	282-333		Material obtained from Prof. H. Schäfer of Münster, West Germany; synthesized through transport reactions; in form of small platelets and tested as received; lattice parameter reported at 293.3 K as 4.240072 Å.
5	852	Houska, C.R.	1965	X	298-773	$TiN_{0.59}$	84.63 Ti, 14.67 N, 0.62 O, 0.11 C, 0.09 Fe, 0.06 Al, 0.02 Sn, 0.01 each Cr, Cu, Mn, Ni, and Si; prepared by passing NH_3 over TiH_2 in a recrystallized alumina boat, ZrH_2 getters used at each end of the tube; sintered powder crushed finer than 325 mesh powder in a steel mill; pressed into 2.86 x 1.27 x 0.48 cm briquettes at 8800 psi; heated in a tungsten boat to 1493 K for 3 hr in vacuum; lattice parameter reported at 298 K as 4.2216 Å.
6	852	Houska, C.R.	1965	X	298-773	$TiN_{0.78}$	Similar to the above specimen; 80.76 Ti, 18.26 N, 0.69 O, 0.11 C, 0.07 Fe, 0.04 Sn, 0.03 Ni, 0.01 each Cr, Cu, Mn, and Pd; 8.48 parts of $TiN_{0.59}$; pressed into a briquette at 994 kg/cm^2, heated in vacuum for 1 hr at 1573 K, 1.25 hr at 1698 K and 1.25 hr at 1833 K; lattice parameter reported at 298 K as 4.2307 Å.
7*	318	Neel, D.S., Pears, C.D., and Oglesby, S., Jr.	1962		294-2866	General Astrometals Corp.	Before exposure 81.3 Ti, 17.0 N, 0.87 C, and 0.4 Fe, after eposure 77.6 Ti, 18.9 N, and 1.02 C; initial length 4.82 cm, final length 4.68 cm; hot-pressed; run SRI-E20; density before exposure at 298 K 4.78 g cm^{-3} by ASTM method B311-58; after exposure 4.59 g cm^{-3}; measured in helium atmosphere.
8*	318	Neel, D.S., et al.	1962		2866,294	General Astrometals Corp.	The above specimen; expansion measured with decreasing temperature.
9	94	Brooksbank, D. and Andrews, K.W.	1968	X	296-969		Powder sample; electrolytically extracted in ferric chloride solution from an 18% Cr - 10% Ni steel containing 0.043% C, 0.4% Ti, and 0.04% N, after a solution treatment of 4 hr at 1573 K, WQ; small contamination by Ti(C,N) in sample; CuKα radiation with 3-4 hr exposure times; camera furnace at pressure of ~10^{-3} torr.
10	842	Timofeeva, I.I. and Shvedova, L.K.	1971	X	93-300	$TiN_{0.98}$	Chemically pure < 0.01 moisture and impurities, made by nitriding at 1173-1873 K for 2-6 hr, then hot pressed in argon atmosphere; nitrogen composition determined by Kjeldahl method; lattice parameter reported at 73 K as 4.2401 Å; 4.2440 Å at 293 K determined by graphical interpolation.
11*	842	Timofeeva, I.I. and Shvedova, L.K.	1971	X	93-300	$TiN_{0.92}$	Similar to the above specimen except different composition; lattice parameter reported at 93 K as 4.2355 Å; 4.2391 Å at 293 K determined by graphical interpolation.

* Not shown in figure.

SPECIFICATION TABLE 315. THERMAL LINEAR EXPANSION OF TITANIUM NITRIDE TiN (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
12	842	Timofeeva, I. I. and Shvedova, L. K.	1971	X	93-300	$TiN_{0.85}$	Similar to the above specimen except different composition; lattice parameter reported at 93 K as 4.2336 Å; 4.2365 Å at 293 K determined by graphical interpolation.
13*	842	Timofeeva, I. I. and Shvedova, L. K.	1971	X	93-300	$TiN_{0.83}$	Similar to the above specimen except different composition; lattice parameter reported at 93 K as 4.2321 Å; 4.2549 Å at 293 K determined by graphical interpolation.
14*	842	Timofeeva, I. I. and Shvedova, L. K.	1971	X	93-300	$TiN_{0.68}$	Similar to the above specimen except different composition; lattice parameter reported at 93 K as 4.2294 Å; 4.2320 Å at 293 K determined by graphical interpolation.

* Not shown in figure.

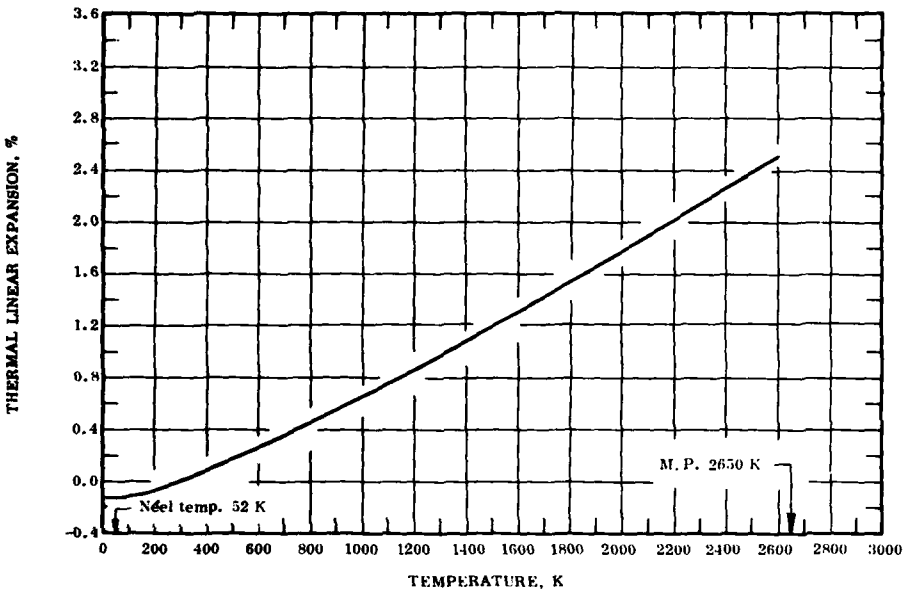
DATA TABLE 315. THERMAL LINEAR EXPANSION OF TITANIUM NITRIDE TiN

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.000
1029	0.600
1284	0.850
1534	1.110
1629	1.270
CURVE 2	
273	-0.0188
1273	0.9212
CURVE 3	
283	-0.002
293	0.000
303	0.009
313	0.014
323	0.018
333	0.027
CURVE 4*	
282.6	-0.009
293.3	0.000
303.0	0.006
312.6	0.011
323.3	0.021
333.3	0.026
CURVE 5	
298	0.0038*
523	0.166
773	0.370
CURVE 6	
298	0.0032*
523	0.141
773	0.347
CURVE 7*	
294	0.00
1224	0.61
1644	0.93
1899	1.06
1922	0.97
2033	0.84
2088	0.55
2088	0.49
2310	0.50
2394	0.20
2644	-0.03
2772	-0.25
2772	-0.51
2866	-0.61
CURVE 8*	
2866	-0.61
294	-2.62
CURVE 9	
296	0.002*
336	0.030*
376	0.061
427	0.096
476	0.125
574	0.214
673	0.330
773	0.407
873	0.502
922	0.572
969	0.650
CURVE 10	
93	-0.093
293	0.000*
300	0.003*
CURVE 11*	
93	-0.0866
293	0.000
300	0.003
CURVE 12	
93	-0.068
293	0.000*
300	0.002*
CURVE 13*	
93	-0.068
293	0.000
300	0.002
CURVE 14*	
93	-0.061
293	0.000
300	0.002

* Not shown in figure.

FIGURE AND TABLE NO. 316R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF URANIUM NITRIDE UN



RECOMMENDED VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

T	$\Delta L/L_0$	α
5	-0.131	0.3
25	-0.131	1.0
50	-0.131	2.0
75	-0.121	2.8
100	-0.114	3.6
150	-0.092	5.0
200	-0.065	6.2
250	-0.031	7.0
293	0.000	7.4
300	0.006	7.5
400	0.087	8.4
500	0.173	8.8
600	0.262	9.1
700	0.356	9.5
800	0.452	9.8
900	0.552	10.1
1000	0.654	10.4
1200	0.867	10.9
1400	1.089	11.3
1600	1.317	11.5
1800	1.550	11.7
2000	1.786	11.8
2200	2.022	11.8
2400	2.258	11.8
2600	2.491	11.9

REMARKS

The recommended values are based on the data for pure samples (curves 2, 3, 7, 8, and 11). These values are considered accurate to within ± 5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.212 + 6.541 \times 10^{-4}\, T + 2.526 \times 10^{-7}\, T^2 - 4.019 \times 10^{-11}\, T^3 \qquad (293\text{–}2600\ K)$$

The tabulated values for the coefficient of thermal expansion are derived primarily by differentiating the above equation and are considered accurate to about ± 7%.

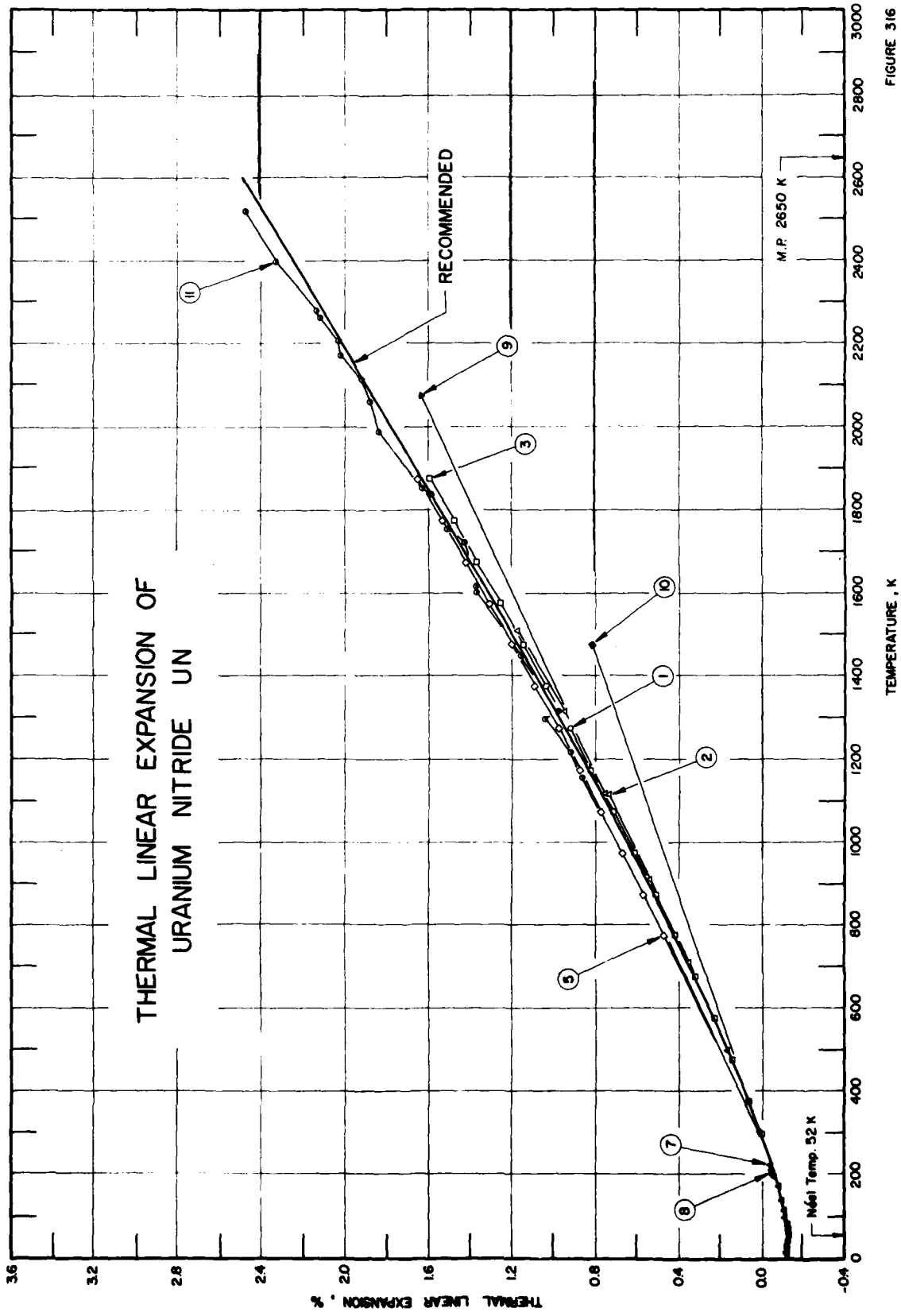

THERMAL LINEAR EXPANSION OF URANIUM NITRIDE UN
RECOMMENDED
M.P. 2650 K
Néel Temp. 52 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
-0.4
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
1
2
3
5
7
8
9
10
11

FIGURE 316

SPECIFICATION TABLE 316. THERMAL LINEAR EXPANSION OF URANIUM MONONITRIDE UN

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	828	Pardue, W. M., Storhok, V. W., and Smith, R. A.	1965	L	298, 1273		Right circular cylindrical specimen approximately 0.069 cm in diameter and 0.942 cm long.
2	734	Taylor, K. M. and McMurtry, C. H.	1961		298-1503		Dimension 7.62 cm x 1.27 cm x 0.63 cm; cold pressed with 844 kg/cm^2 and sintered at 2123 K in vacuum; measured in argon.
3	853	Speidel, E. O. and Keller, D. L.	1963	L	293-1873		Small impurity phases; cold pressed binderless powder pellet isostatically hot pressed 3 hr at 1753 K at 703 kg-cm^{-2} in gas atmosphere, then ground to rod 5.616 cm long x 0.871 cm diameter; density 14.0 g cm^{-3}; expansion measured with increasing temperature.
4*	853	Speidel, E. O. and Keller, D. L.	1963	L	1873-293		The above specimen; expansion measured with decreasing temperature; zero-point correction at 293 K is -0.064%.
5	853	Speidel, E. O. and Keller, D. L.	1963	L	293-1873		The above specimen; expansion measured on second thermal cycle with increasing temperature; zero-point correction at 293 K is -0.064%.
6*	853	Speidel, E. O. and Keller, D. L.	1963	L	1873-293		The above specimen; expansion measured with decreasing temperature; zero-point correction at 293 K is -0.098%.
7	854	Marples, J. A. C.	1969	X	4.7-300		99.86 UN, 0.14 O, 0.04 metallic impurities, no UO_2 found; powder glued to 2 mm thick metal plate with shellac; negative expansion at 52 K attributed to negative magnetic Gruneisen parameter; lattice parameter reported at 293 K as 4.88938 Å.
8	843	Lander, G. H. and Mueller, M. H.	1974	X	200-300		Particle size ~40 μm, crystal structure of NaCl powder was die pressed at 527 kg/cm^2 into flat disk, placed in milled recess in copper sample holder disk covered with 0.005 cm thick Mylar window, sealed with copper frame and resin; lattice parameter reported at 300 K as 4.890 Å.
9	855	Ihara, S., Suzuki, M., and Akimoto, Y.	1970	X	298, 2073	$UC_{0.36}N_{0.64}$	95.3 U, 3.5 N, 1.7 C, 0.04 O; dimension: thin pellets 6 mm diameter x 0.15-0.20 mm thick; expansion measured in argon atmosphere.
10	855	Ihara, S., et al.	1970	X	298, 1473	UN	Similar to the above specimen except 94.4 U, 5.6 N.
11	714	Benz, R. and Farr, J. D.	1971	X	293-2520	UN	Cylindrical; 10 mm diameter; reaction of nitrogen with uranium product was reduced in vacuum to UN powder; mixture was cold pressed into cylinder and annealed for 2 min at 2373 K, then reground with pestle into powder; process repeated three times; the final specimen weight was 1.3 g up to 1873 K, specimen was heated in a 5 torr argon atmosphere; lattice parameter reported at 293 K as 4.890 Å.

* Not shown in figure.

DATA TABLE 316. THERMAL LINEAR EXPANSION OF URANIUM MONONITRIDE UN

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.005
1273	0.921
CURVE 2	
298	0.000
495	0.161
704	0.348
908	0.536
1113	0.735
1115	0.743
1313	0.942
1503	1.169
CURVE 3	
293	0.000
373	0.060
473	0.141
573	0.228
673	0.320
773	0.415
873	0.512
973	0.612
1073	0.716
1173	0.822
1273	0.930*
1373	1.038
1473	1.146
1573	1.255
1673	1.366
1773	1.479
1873	1.595
CURVE 4*	
1873	1.531
1773	1.422
1673	1.314
1573	1.206
1473	1.098
1373	0.991
1273	0.885
1173	0.782
1073	0.680
973	0.580

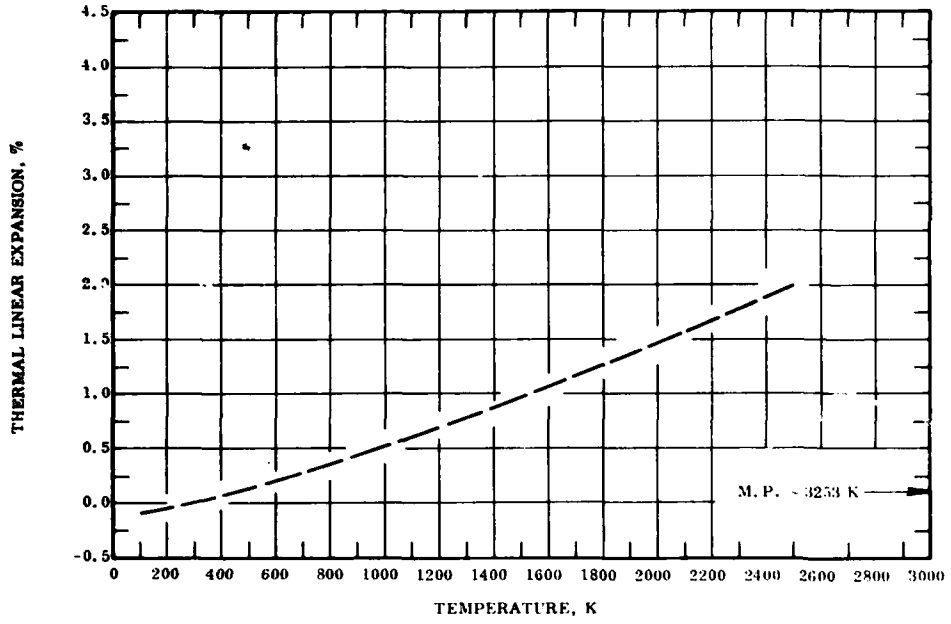
T	$\Delta L/L_0$
CURVE 4 (cont.)*	
873	0.483
773	0.388
673	0.298
573	0.220
473	0.137
373	0.058
293	0.000
CURVE 5	
293	0.064*
373	0.123*
473	0.202*
573	0.288*
673	0.377*
773	0.471
873	0.568
973	0.668
1073	0.771
1173	0.876
1273	0.976
1373	1.091
1473	1.200
1573	1.310
1673	1.421
1773	1.532
1873	1.644
CURVE 6*	
1873	1.546
1773	1.438
1673	1.330
1573	1.222
1473	1.115
1373	1.008
1273	0.902
1173	0.797
1073	0.696
973	0.591
873	0.492
773	0.396
673	0.300
573	0.217
473	0.135
373	0.058
293	0.000

T	$\Delta L/L_0$
CURVE 7	
4.7	-0.123
5.5	-0.122*
15.2	-0.123
22.7	-0.123
29.1	-0.125
34.7	-0.127
43.3	-0.129
52.5	-0.134
63.0	-0.130
79.0	-0.125
95.5	-0.118
109.5	-0.113
134.6	-0.101
166.5	-0.083
192.0	-0.066
220.0	-0.047
293.0	0.000*
300.0	0.004*
CURVE 8	
200	-0.056
293	0.000*
300	0.004*
CURVE 9	
298	0.005*
2073	1.632
CURVE 10	
298	0.003*
1473	0.815
CURVE 11	
293	0.000*
1155	0.87
1214	0.92
1297	1.04
1314	0.98
1445	1.16
1600	1.37
1613	1.37
1721	1.43

T	$\Delta L/L_0$
CURVE 11 (cont.)	
1752	1.51
1835	1.59
1848	1.63
1984	1.84
2059	1.88
2114	1.92
2170	2.025
2205	2.029
2262	2.12
2279	2.14
2396	2.33
2520	2.474

* Not shown in figure.

FIGURE AND TABLE NO. 317R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ZIRCONIUM NITRIDE ZrN



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
100	-0.090	3.3
150	-0.075	4.0
200	-0.050	4.7
250	-0.020	5.3
293	0.000	5.7
300	0.005	5.8
400	0.072	6.5
500	0.141	7.1
600	0.214	7.3
700	0.288	7.6
800	0.365	7.8
900	0.444	8.0
1000	0.525	8.2
1200	0.695	8.7
1400	0.872	9.1
1600	1.058	9.5
1800	1.251	9.9
2000	1.452	10.2
2200	1.660	10.5
2400	1.874	10.9
2500	1.983	11.0

REMARKS

The provisional values are based on the data for samples with approximate compositions of (85 ±2) Zr and (12 ±2) N (curves 1, 3, 5, 13, and 14). These values are considered accurate to within ±7% at temperatures below 1500 K and ±10% above 1500 K. The provisional values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.182 + 5.816 \times 10^{-4}\, T + 1.333 \times 10^{-7}\, T^2 - 7.822 \times 10^{-12}\, T^3 \quad (293\text{-}2500\ K)$$

The tabulated values for the coefficient of thermal expansion are calculated primarily by differentiating the above equations and are considered accurate to about ±15%.

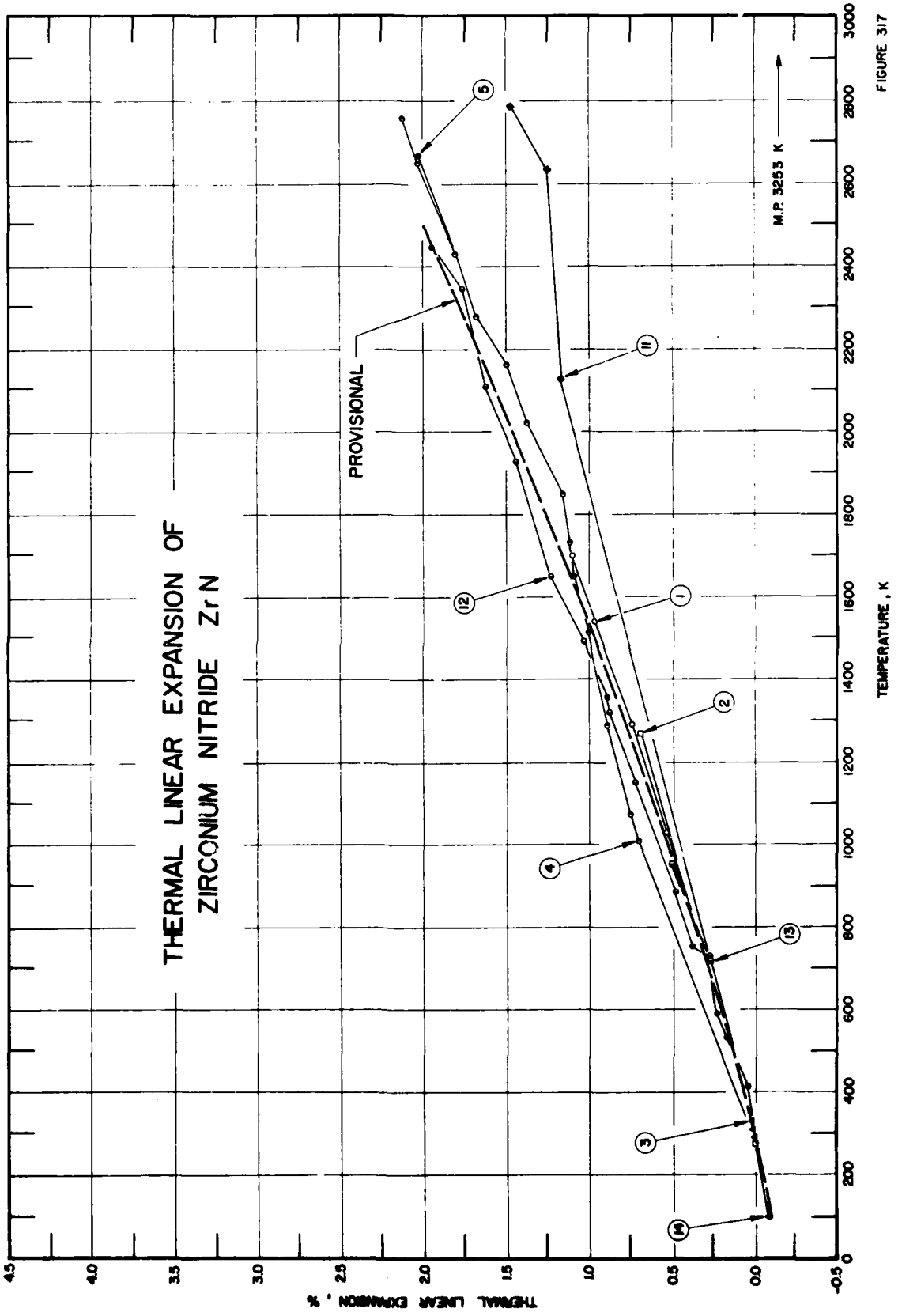

THERMAL LINEAR EXPANSION OF
ZIRCONIUM NITRIDE ZrN
PROVISIONAL
M.P. 3253 K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
1
2
3
4
5
11
12
13
14

FIGURE 317

SPECIFICATION TABLE 317. THERMAL LINEAR EXPANSION OF ZIRCONIUM NITRIDE ZrN

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	420	Houska, C.R.	1965	X	298-1699	$ZrN_{0.93}$	85.76 Zr, 12.27 N, 1.5 O, 0.21 C, 0.02 Al, 0.02 Cr, 0.01 Fe, and 0.01 Si; by pressing less than 325 mesh powders at 1124.8 kg/cm^2; heated in a flowing NH_3 atmosphere to 1623 K for 2 hr; CuKα radiation used; data obtained from (422) and (511/333).
2	3	Steele, S.R., Pappis, J., Schilling, H., and Hagan, L.	1967		273,1273		Specimen deposited at 1973 K from the vapor.
3	856	Straumanis, M.E., Faumce, C.A., and James, W.J.	1966	X	283-333		86.13 Zr, 11.6 N, 2.0 Hf, 0.27 metallic impurities; powder sample; from the Carborundum Metals Co., Akron, N.Y.; chromium Kβ radiation giving a β331 line suitable to measure precisely lattice constants; density at 25 C 6.881 ± 0.003 g cm^3.
4	318	Neel, D.S., Pears, C.D., and Oglesby, S., Jr.	1962		294-2755		Before exposure 86.9 Zr, 12.8 N_2, and 0.1 Fe; after exposure 86.5 Zr, 10.8 N_2, and 1.19 C; initial length 7.54 cm; final length 7.70 cm; obtained from General Electric Co.; pressed and sintered; specimen broken on post inspection; Run SRI-E24; density in g cm^{-3} at 298 K before exposure 7.2 by all three methods mentioned below; after exposure 6.8 by ASTM method B311-58, 6.7 by wax-coating specimen, and 7.0 by immersion in xylene; measured in helium atmosphere; lattice parameter reported at 293 K as 4.57536 Å; reported error 2%.
5	318	Neel, D.S., et al.	1962		2755,2666		First cooling of above specimen.
6*	318	Neel, D.S., et al.	1962		2666-2822		Second heating of above specimen.
7	318	Neel, D.S., et al.	1962		2822-294		Second cooling of above specimen.
8*	318	Neel, D.S., et al.	1962		2661-2836		Third heating of above specimen.
9*	318	Neel, D.S., et al.	1962		2836,2433		Third cooling of above specimen.
10*	318	Neel, D.S., et al.	1962		2433-2783		Final heating of above specimen.
11	318	Neel, D.S., et al.	1962		2783-294		Final cooling of above specimen.
12	64	Hedge, J.C., Kostenko, C., and Lang, J.I.	1963		299-2433		84.6 Zr, 13.5 N, 0.8 H, 0.4 Si, 0.2 Fe, and 0.5 alkali metal oxides; dimensions 1.27 cm diameter by 15.24 long; Norton Co.; hot pressed and fired at 2373 K; density 5.76 g cm^3; measured in argon gas with heating rate of approximately 258 K per min; reported error 2%.
13	857	Baker, T.W., Spindler, W.E., and Wilkinson, D.	1958	X	290-953		87.4 Zr, 12.09 N, 0.19 Mg; prepared by heating about 10 g Zr powder surrounded by a nitrogen gas of low oxygen content for 4 hr at 1523 K in an alumina boat; measured in vacuum of 1 x 10^{-4} torr; 4.5745 Å at 290 K.
14	842	Timofeeva, I.I. and Shvedova, L.K.	1971	X	93-300	$ZrN_{0.99}$	Chemically pure with < 0.01 moisture and impurities; made by nitriding at 1173-1873 K for 2-6 hr, then hot pressed in argon atmosphere; composition determined by Kjeldhol method; lattice parameter reported at 93 K as 4.5735 Å; 4.5771 Å at 293 K determined by graphical interpolation.
15*	842	Timofeeva, I.I. and Shvedova, L.K.	1971	X	93-300	$ZrN_{0.86}$	Similar to the above specimen except different composition; lattice parameter reported at 93 K as 4.5739 Å; 4.5776 Å at 293 K determined by graphical interpolation.
16*	842	Timofeeva, I.I. and Shvedova, L.K.	1971	X	93-300	$ZrN_{0.77}$	Similar to the above specimen except different composition; lattice parameter reported at 93 K as 4.5744 Å; 4.5785 Å at 293 K determined by graphical interpolation.

* Not shown in figure.

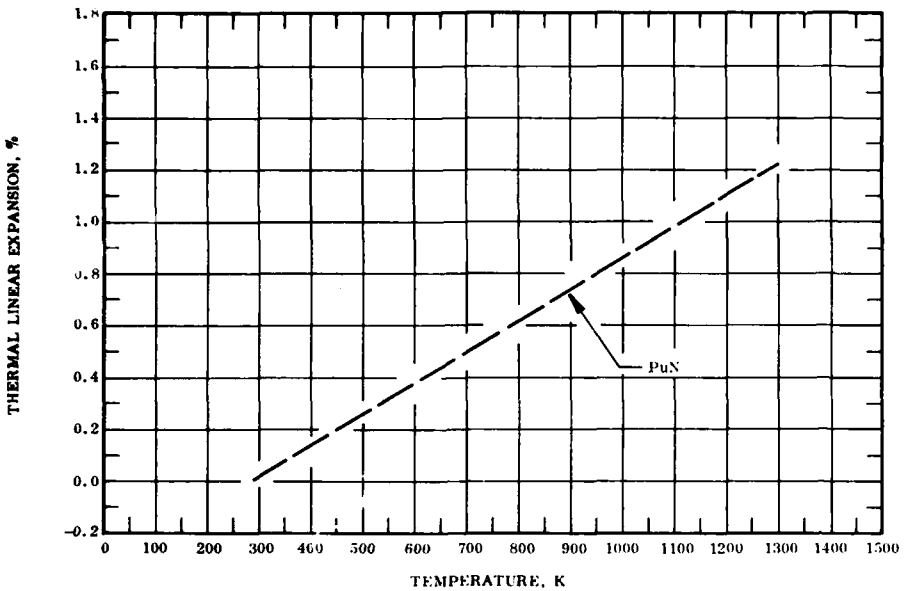
DATA TABLE 317. THERMAL LINEAR EXPANSION OF ZIRCONIUM NITRIDE ZrN

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.000
1030	0.531
1288	0.747
1539	0.965
1699	1.100
CURVE 2	
273	-0.014
1273	0.686
CURVE 3	
283	-0.007
293	0.000*
303	0.003
313	0.004*
323	0.015
333	0.018*
CURVE 4	
294	0.00*
1005	0.70
1072	0.75
1283	0.87
1510	1.00
1644	1.08
1733	1.11
1844	1.15
2019	1.37
2160	1.49
2277	1.67
2427	1.81
2644	2.03
2755	2.11
CURVE 5	
2755	2.11*
2666	2.03
CURVE 6*	
2666	2.03
2733	2.14
CURVE 6 (cont.)*	
2788	2.24
2797	2.31
2822	2.72
CURVE 7*	
2822	2.72
2661	2.75
294	0.00
CURVE 8*	
2661	2.75
2700	2.88
2830	3.04
2836	3.19
CURVE 9*	
2836	3.19
2433	2.84
CURVE 10*	
2433	2.84
2697	3.03
2783	3.16
2783	3.26
CURVE 11	
2783	1.46
2627	1.25
2133	0.92
294	0.00*
CURVE 12	
299	0.002*
414	0.046
534	0.158
590	0.224
629	0.264
749	0.375
884	0.467
1152	0.702
CURVE 12 (cont.)	
1319	0.864
1357	0.893
1490	1.026
1650	1.194
1925	1.440
2113	1.625
2342	1.760
2443	1.947
CURVE 13	
290	-0.002
718	0.260
953	0.479
CURVE 14	
93	-0.082
293	0.000*
300	0.002*
CURVE 15*	
93	-0.082
293	0.000
300	0.002
CURVE 16*	
93	-0.090
293	0.000
300	0.003

* Not shown in figure.

FIGURE AND TABLE NO. 318R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF MISCELLANEOUS NITRIDES



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	PuN	
T	$\Delta L/L_0$	α
293	0.000	11.8
300	0.009	11.8
400	0.128	11.9
500	0.247	12.0
600	0.368	12.1
700	0.489	12.1
800	0.611	12.2
900	0.733	12.3
1000	0.856	12.3
1100	0.979	12.3
1200	1.102	12.4
1300	1.226	12.4

REMARKS

The provisional values are considered accurate to within ± 7% at temperatures below 800 K and ± 10% above 800 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.342 + 1.154 \times 10^{-3}\ T + 5.561 \times 10^{-8}\ T^2 - 1.205 \times 10^{-11}\ T^3$$

The tabulated values for the coefficient of thermal expansion are calculated primarily by differentiating the above equation and are considered accurate to about ± 10%.

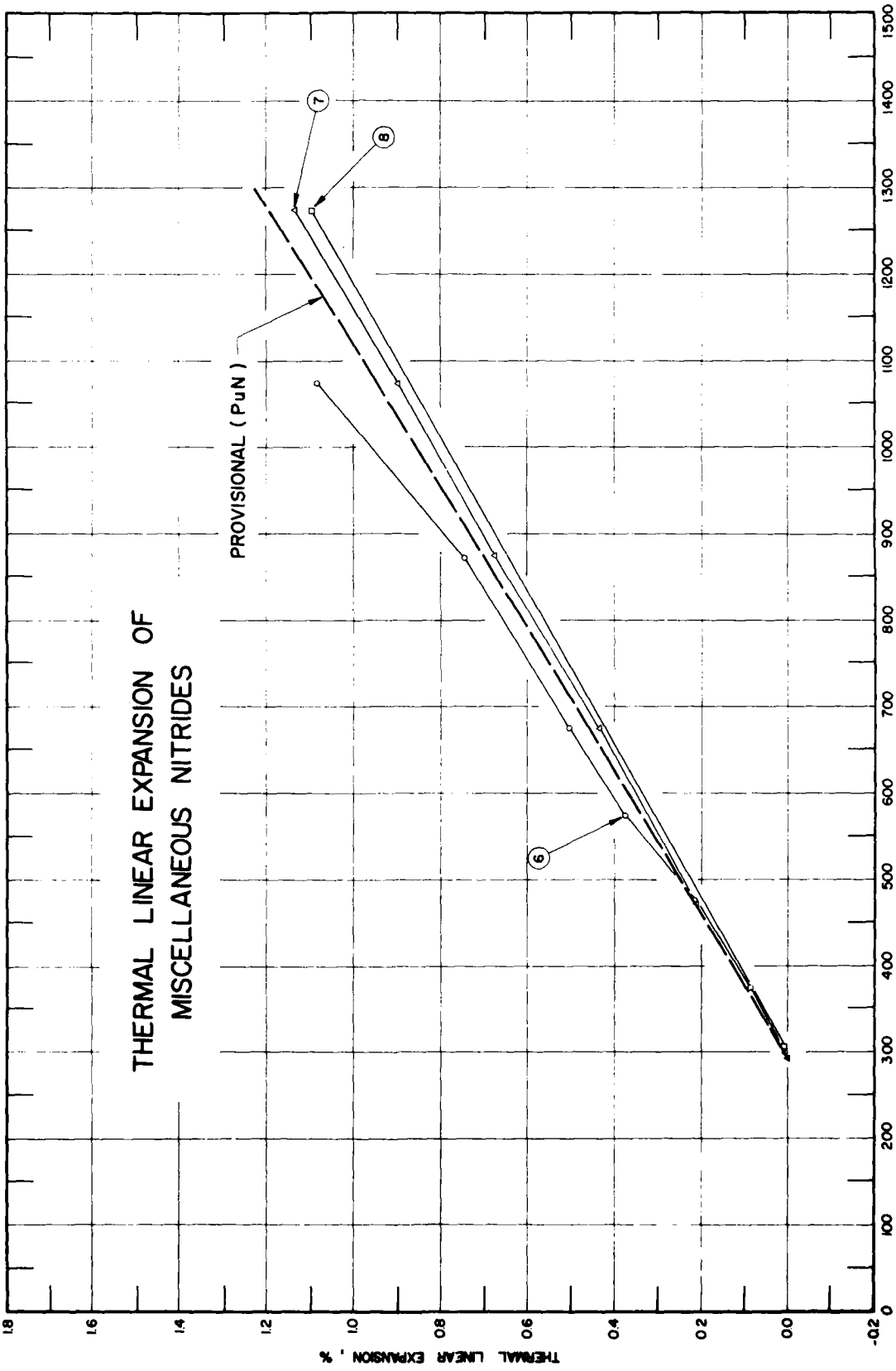

THERMAL LINEAR EXPANSION OF
MISCELLANEOUS NITRIDES
PROVISIONAL (PuN)
6
7
8
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
-.02
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 318

SPECIFICATION TABLE 318. THERMAL LINEAR EXPANSION OF MISCELLANEOUS NITRIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	318	Neel, D.S., Pears, C.D., and Oglesby, S., Jr.	1962		294-2872	HfN	Hafnium nitride; before exposure 93.6 Hf, 7.5 N; Carborundum Co.; initial length 13.62 cm, final length 7.47 cm; elements found by semi-quantitative emission spectrography 0.2 Mg, 0.3 Ca, and 3.4 Zr, after exposure 93.6 Hf, 7.5 N, and 0.07 C; hot pressed and fired near 3866 K; specimen broken on post inspection; Run SRI-E29; density in g cm^{-3} at 298 K before exposure 12.7 by ASTM method B311-58 and by wax-coating specimen and 12.4 by immersion in xylene, after exposure 12.4 by all three methods mentioned above; measured in helium gas; reported error 2%.
2*	318	Neel, D.S., Pears, C.D., and Oglesby, S., Jr.	1962		2872-294	HfN	Hafnium nitride; cooling of above specimen.
3*	842	Timofeeva, I.I. and Shvedova, L.K.	1971	X	93-300	$HfN_{1.00}$	Hafnium nitride; chemically pure < 0.01 moisture and impurities made by nitriding at 1173-1873 K for 2-6 hr, then hot pressed in argon atmosphere; nitrogen composition determined by Kjeldhal method; lattice parameter reported at 93 K as 4.5061 Å; 4.5099 Å at 293 K determined by graphical interpolation.
4*	843	Landers, G.H. and Mueller, M.H.	1974	X	200-300	NpN	Neptunium nitride; particle size ~40 μm; crystal structure of NaCl; powder; was die pressed at 527 kg/cm^2 into flat disk placed in milled recess in copper sample holder disk covered with 1005 cm thick Mylar window, sealed with copper frame and resin lattice parameter reported at 300 K as 4.897 Å.
5*	842	Timofeeva, I.I. and Shvedova, L.K.	1971	X	93-300	$NbN_{0.95}$	Niobium nitride; chemically pure < 0.01 moisture and impurities; made by nitriding at 1173-1873 K for 2-6 hr, then hot pressed in argon atmosphere; nitrogen composition determined by Kjeldahl method; lattice parameter reported at 93 K as 4.3854 Å; 4.3887 Å at 293 K determined by graphical interpolation.
6	827	Carroll, D.F.	1963	X	299-1073	PuN	Plutonium nitride; synthesized by decomposing 325 mesh plutonium hydride in vacuum at 873 K and immediately passing gettered nitrogen at 1 atmosphere pressure; expansion measured in vacuum; no phase change within temperature range; lattice parameter reported at 299 K as 4.9060 Å; 4.9057 Å at 293 K determined by graphical extrapolation.
7	137	Kruger, O.L. and Moser, S.B.	1965	L	302-1275	PuN	Plutonium nitride; zero-point correction is 0.011% at 293 K.
8	828	Pardue, W.M., Storhok, V.W., and Smith, R.A.	1965	L	298,1273	PuN	Plutonium nitride; right circular cylindrical specimen approximately 6.096 mm diameter x 8.27 mm long.
9	643	Hajek, B., Brozek, V., and Duvigneaud, P.H.	1973	L	293-1273	ScN	Scandium nitride; lattice parameter reported at 293 K as 4.505 Å.
10*	63	Pears, C.D. and Oglesby, S.	1962		288-3083	TaN	Tantalum nitride; 95.7 Ta, 3.5 N, 0.13 C; initial length 5.60 cm; final length 5.66 cm; Carborundum Co.; elements found by semi-quantitative emission spectrography before exposure 0.3 Fe, 0.2 Si, 0.1 Mg, after exposure 95.5 Ta, 3.1 N, and 0.95 C; hot pressed; specimen cracked on post inspection; Run No. E2; density in g cm^{-3} at 298 K before exposure 13.4 by ASTM method B311-58, 13.3 by wax-coating specimen, 13.7 by immersion in xylene, after exposure 13.4 by ASTM method, 13.6 by wax-coating specimen, and 14.6 by immersion in xylene; measured in helium atmosphere; zero-point correction is -0.002% at 293 K; reported error 5%.

* Not shown in figure.

SPECIFICATION TABLE 318. THERMAL LINEAR EXPANSION OF MISCELLANEOUS NITRIDES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
11*	63	Pears, C.D. and Oglesby, S.	1962		2838-294	TaN	Tantalum nitride; cooling of above specimen; zero-point correction is 1.74% at 293 K.
12*	842	Timofeeva, I.I. and Shvedova, L.K.	1971	X	93-300	TaN	Tantalum nitride; chemically pure specimen with < 0.01 moisture and impurities made by nitriding at 1173-1873 K for 2-6 hr; hot pressed in argon atmosphere; composition determined by Kjeldahl method; expansion measured along a-axis; lattice parameter reported at 93 K as 5.7130 Å; 5.71590 Å at 293 K determined by graphical interpolation.
13*	842	Timofeeva, I.I. and Shvedova, L.K.	1971	X	93-300	TaN	Tantalum nitride; same as above specimen; expansion measured along c-axis; lattice parameter reported at 93 K as 2.9082 Å; 2.9098 Å at 293 K determined by graphical interpolation.
14*	172	Aronson, S., Cisney, E., and Gingerich, K.A.	1967	X	1089-1574	ThN	Thorium nitride; sample prepared from Th_3N_4 by decomposition in vacuo at 1773 K and Th_3N_4 obtained by heating thorium metal powder in nitrogen gas at 1173 K; CuKα radiation; (422), (511), (531), and (600) lines used; melting point 3063 K.
15*	842	Timofeeva, I.I. and Shvedova, L.K.	1971	X	93-300	$VN_{0.98}$	Vanadium nitride; chemically pure < 0.01 moisture and impurities made by nitriding at 1173-1873 K for 2-6 hr then hot pressed in argon atmosphere; nitrogen composition determined by Kjeldahl method; lattice parameter reported at 93 K as 4.1262 Å; 4.1306 Å at 293 K determined by graphical interpolation.
16*	855	Ihara, S., Suzuki, M., and Akimoto, Y.	1970	X	293-1773	$U_{0.79}Ce_{0.21}C_{0.4}N_{0.6}$	Uranium cerium + carbon nitride; 82.0 U, 12.5 Ce, 3.6 N, 2.0 C, 0.03 O; dimension: thin pellet, 6 mm diameter x 0.15-0.20 mm thick; expansion measured in argon atmosphere.
17*	855	Ihara, S., et al.	1970	X	293-1773	$U_{0.80}Ce_{0.2}C_{0.35}N_{0.65}$	Uranium cerium + carbon nitride; similar to the above specimen except 81.8 U, 12.4 Ce, 4.1 N, 1.9 C, and 0.07 O.
18*	855	Ihara, S., et al.	1970	X	293-1773	$U_{0.84}Ce_{0.20}C_{0.33}N_{0.67}$	Uranium cerium + carbon nitride; similar to the above specimen except 82.0 U, 12.3 Ce, 4.2 N, 1.8 C, and 0.04 O.
19*	828	Pardue, W.M., Storhok, V.W., and Smith, R.A.	1965	L	298,1273	(U + Pu)N	Uranium nitride + plutonium nitride; 84.0 U and 16.0 Pu; $(U_{0.85}Pu_{0.15})N$; right cylindrical specimen 0.60 cm diameter and 0.95 cm long.
20*	858	Keller, D.L.	1968		293-1448	(U + Pu)N	Uranium nitride + plutonium nitride; 49.0 U and 51.0 Pu; $(U_{0.50} + Pu_{0.50})N$.

* Not shown in figure.

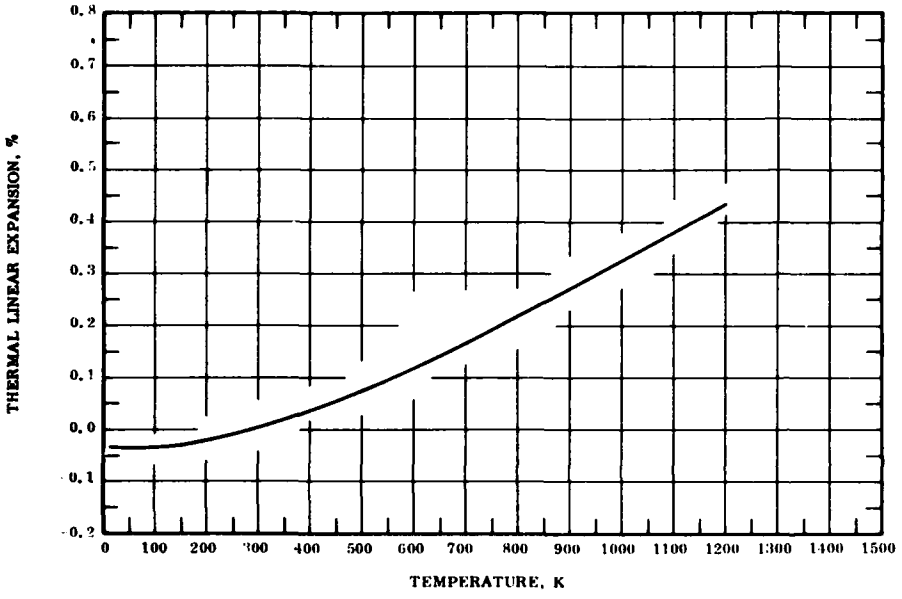
DATA TABLE 318. THERMAL LINEAR EXPANSION OF MISCELLANEOUS NITRIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
294	0.00
810	0.34
1249	0.58
1383	0.71
1555	0.97
1677	1.22
1788	1.19
1872	0.92
2060	0.55
2149	0.57
2294	0.55
2422	0.45
2547	0.25
2772	-0.33
2872	-0.73
CURVE 2*	
2872	1.600
294	0.000
CURVE 3*	
93	-0.084
293	0.000
300	0.004
CURVE 4*	
200	-0.051
293	0.000
300	0.003
CURVE 5*	
93	-0.077
293	0.000
300	0.002
CURVE 6	
299	0.006
374	0.084
477	0.218
574	0.377
673	0.508
CURVE 6 (cont.)*	
876	0.744
1073	1.082
CURVE 7	
302	0.011
471	0.214
674	0.437
872	0.672
1074	0.899
1275	1.135
CURVE 8	
298	0.006
1273	1.098
CURVE 9	
293	0.000
773	0.155
1273	0.444
CURVE 10*	
288	-0.002
533	0.119
766	0.236
1075	0.409
1345	0.531
1642	0.636
1896	0.763
2118	0.926
2200	0.908
2363	1.010
2432	0.972
2722	1.187
3083	1.298
CURVE 11*	
2838	3.05
2566	2.00
294	0.00
CURVE 12*	
93	-0.050
293	0.000
300	0.001
CURVE 13*	
93	-0.056
293	0.000
300	0.002
CURVE 14*	
1089	0.566
1133	0.603
1184	0.651
1263	0.698
1338	0.755
1338	0.771
1414	0.838
1488	0.874
1530	0.916
1574	0.969
CURVE 15*	
93	-0.104
293	0.000
300	0.004
CURVE 16*	
293	0.000
298	0.004
1773	1.472
CURVE 17*	
293	0.000
298	0.004
1773	1.413
CURVE 18*	
293	0.000
298	0.004
1773	1.320
CURVE 19*	
298	0.0049
1273	0.882
CURVE 20*	
293	0.000
323	0.026
373	0.073
473	0.168
573	0.266
673	0.369
773	0.477
873	0.585
973	0.696
1073	0.812
1173	0.928
1273	1.045
1373	1.162
1448	1.252

* Not shown in figure.

FIGURE AND TABLE NO. 319R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF BORON PHOSPHIDE BP



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
5	-0.031	0.01
25	-0.032	0.03
50	-0.032	0.07
75	-0.032	0.15
100	-0.031	0.25
150	-0.027	1.0
200	-0.021	1.8
250	-0.011	2.4
293	0.000	2.9
300	0.002	2.9
400	0.036	3.7
500	0.075	4.2
600	0.119	4.7
700	0.167	5.0
800	0.218	5.2
900	0.271	5.3
1000	0.325	5.4
1100	0.380	5.5
1200	0.434	5.6

REMARKS

The recommended values are considered accurate to within ±5% and are represented approximately by the following equations:

$\Delta L/L_0 = -3.091 \times 10^{-2} - 3.751 \times 10^{-5} T + 3.551 \times 10^{-7} T^2 + 4.539 \times 10^{-10} T^3$ (5-300 K)

$\Delta L/L_0 = -5.770 \times 10^{-2} + 7.841 \times 10^{-5} T + 4.460 \times 10^{-7} T^2 - 1.416 \times 10^{-10} T^3$ (293-1200 K)

The tabulated values for the coefficient of thermal expansion above 100 K are based on the experimental data and below 100 K the values are obtained by differentiating the above equation. These values are considered accurate to about ±7%.

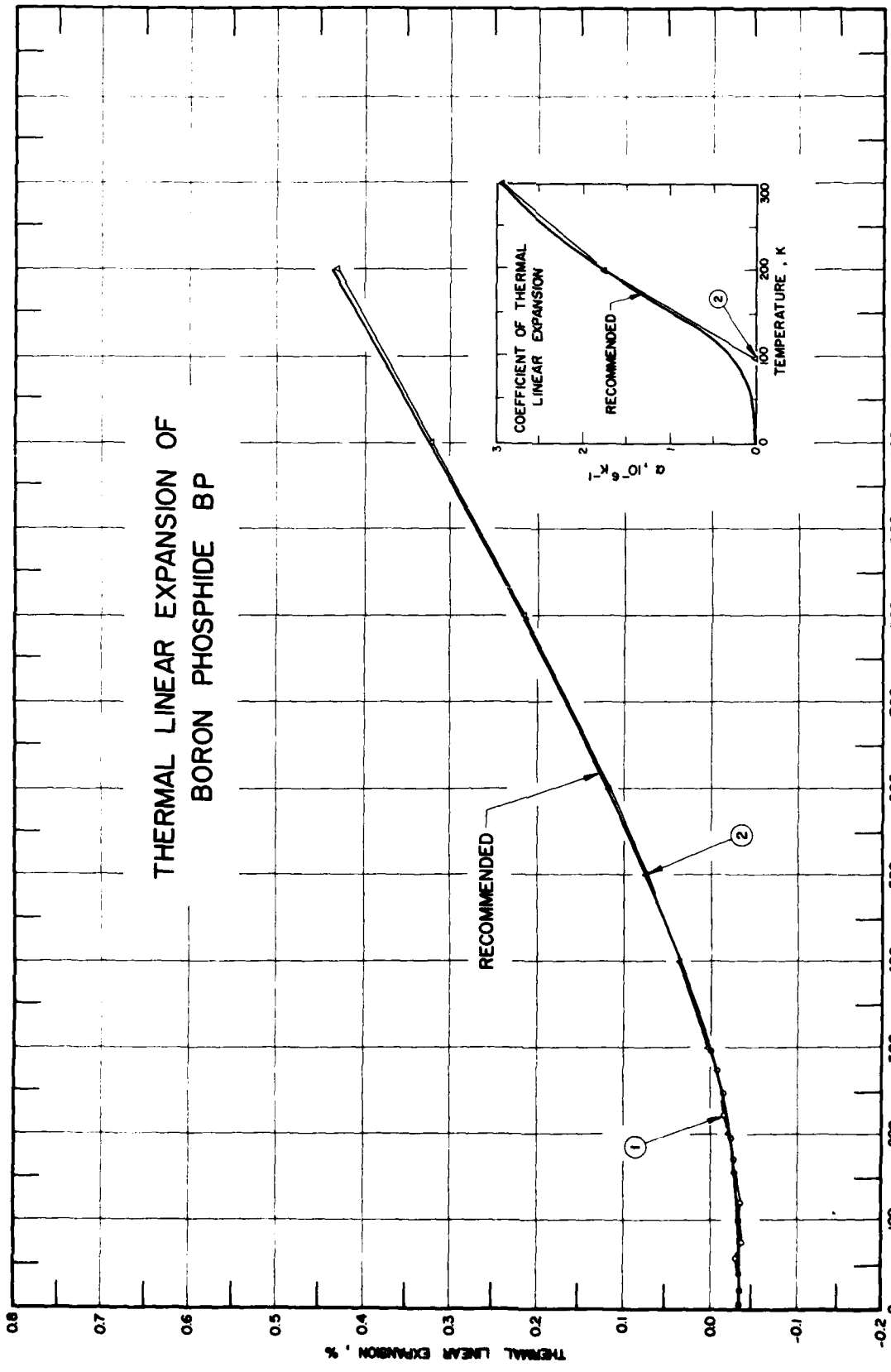

THERMAL LINEAR EXPANSION OF
BORON PHOSPHIDE BP
RECOMMENDED
1
2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
RECOMMENDED
α , 10⁻⁶ K⁻¹
TEMPERATURE , K

FIGURE 319

SPECIFICATION TABLE 319. THERMAL LINEAR EXPANSION OF BORON PHOSPHIDE BP

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	160	Schaake, H. F.	1969	X	4.2-296		Specimen from General Electric Corp.; ground to < 325 mesh, 10% Iridium added for calibration, pressed into copper sample holder; x-ray analysis showed only cubic structure; lattice parameter reported at 296 K as 4.5373 Å; 4.5372 Å at 293 K determined by graphical interpolation.
2	818	Slack, G.A. and Bartram, S.F.	1974	X	0-1200		Particle size ~ 15 μm, made by crushing numerous small crystals grown from liquid palladium; lattice parameter reported at 297 K as 4.5383 Å.

DATA TABLE 319. THERMAL LINEAR EXPANSION OF BORON PHOSPHIDE BP

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 2 (cont.)‡	
4.2	-0.0312	196	-0.0237	100	-0.031*
22	-0.0315	222	-0.0165	200	-0.022
40	-0.0312	248	-0.0143	300	0.002
58	-0.0295	273	-0.0092	400	0.035*
77.4	-0.0363	296	0.0014	500	0.074*
100	-0.0328			600	0.118*
120	-0.0339	CURVE 2‡		800	0.216*
155	-0.0299			1000	0.322*
170	-0.0286	0	-0.031	1200	0.432*

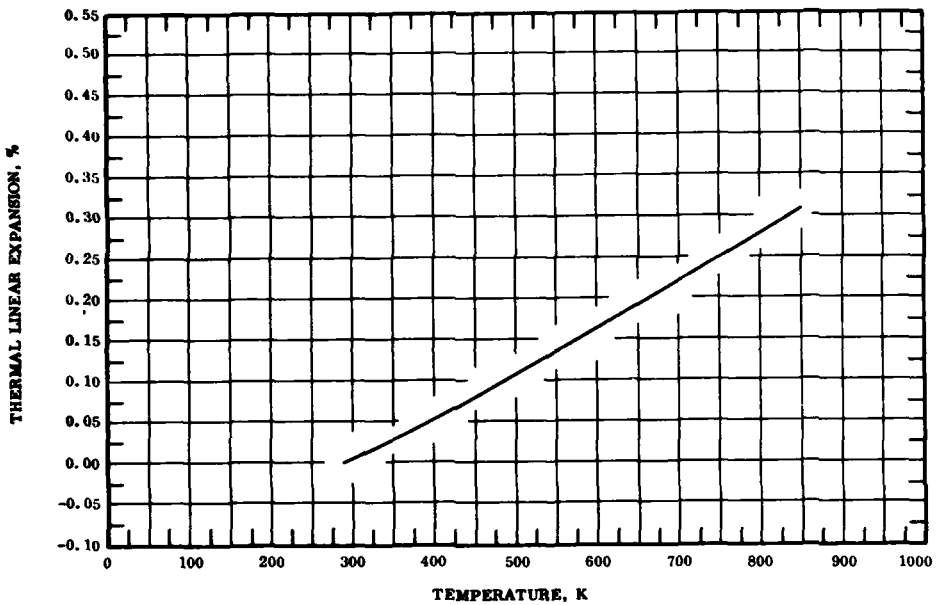
DATA TABLE 319. COEFFICIENT OF THERMAL LINEAR EXPANSION OF BORON PHOSPHIDE BP

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α
CURVE 2‡		CURVE 2 (cont.)‡	
0	0.00	500	4.21
100	0.00	600	4.65
200	1.77	800	5.17
300	2.94	1000	5.42
400	3.65	1200	5.54

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 320R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF GALLIUM PHOSPHIDE GaP



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	4.7
300	0.003	4.7
350	0.028	5.0
400	0.053	5.2
450	0.080	5.4
500	0.107	5.5
550	0.135	5.7
600	0.163	5.8
650	*0.192*	*5.8*
700	0.222	5.9
750	0.251	5.9
800	0.280	6.0
850	0.309	6.0

REMARKS

The recommended values are considered accurate to within ± 5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.110 + 2.611 \times 10^{-4}\, T + 4.445 \times 10^{-7}\, T^2 - 2.023 \times 10^{-10}\, T^3$$

The tabulated values for the coefficient of thermal expansion are primarily derived by differentiating the above equation and are considered accurate to about ± 10%.

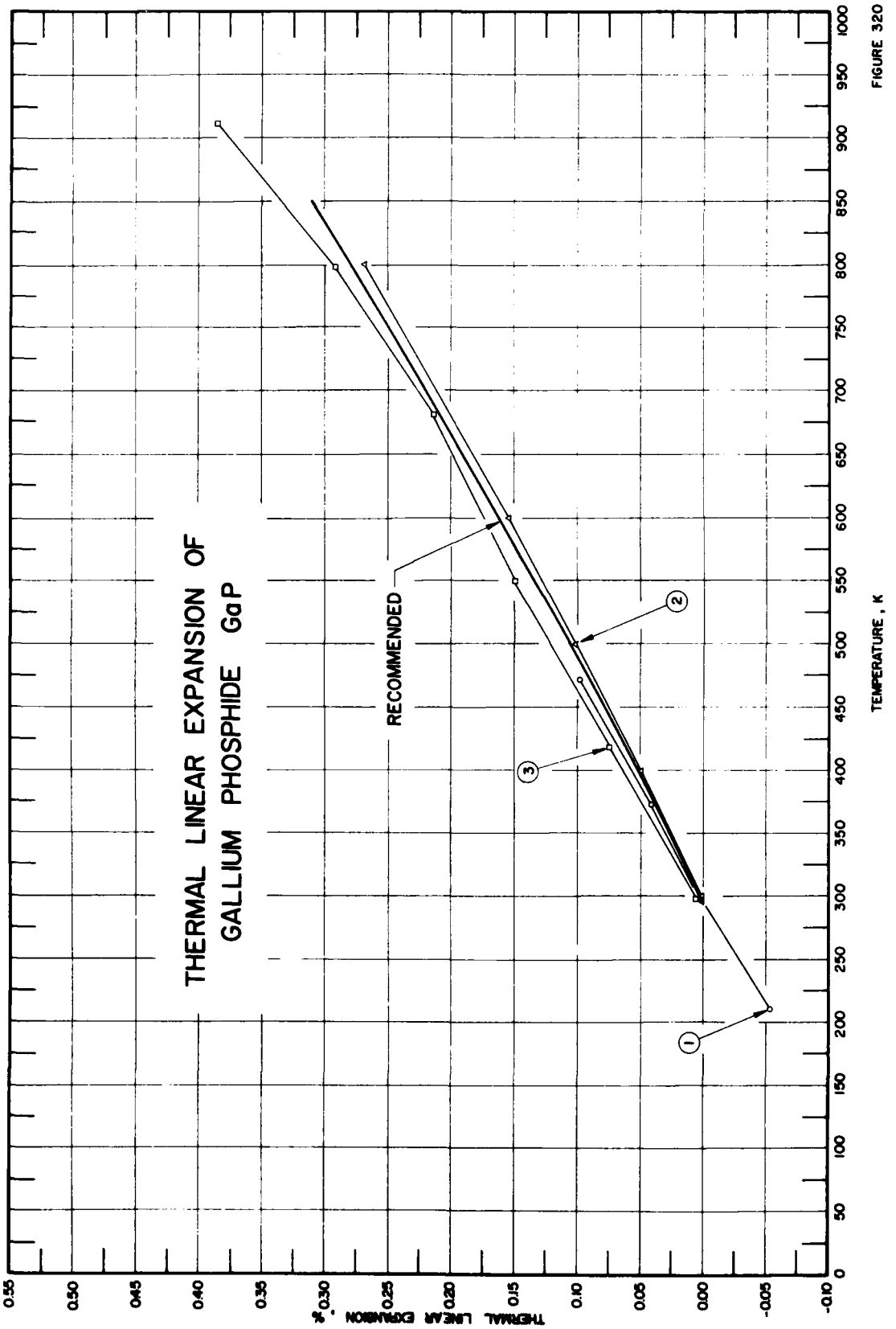

THERMAL LINEAR EXPANSION OF
GALLIUM PHOSPHIDE GaP
RECOMMENDED
1
2
3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 320

SPECIFICATION TABLE 320. THERMAL LINEAR EXPANSION OF GALLIUM PHOSPHIDE GaP

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	860	Pierron, E.D., Parker, D.C., and McNeely, J.B.	1967	X	211–473		30.71 P and 69.29 Ga; total impurity < 0.0003 percent; sample synthesized from Aluminum-Industrie-Aktien-Gesellschaft 99.9999 percent gallium and American Agricultural Chemical Co. semiconductor-grade elemental phosphorous; ground to 44 μ grain; lattice parameter reported at 297 K as 5.4495 Å; 5.4491 Å at 293 K determined by graphical interpolation.
2	818	Slack, G.A. and Bartram, S.F.	1974	X	0–800		Data is summary of literature search conducted by authors and represented here as smoothed data.
3	861	Kudman, I. and Daff, D.J.	1972	X	298–912	GaP	Specimen made by grinding to mass through 500 mesh loaded into 30 mm ID quartz capillaries and sealed; lattice parameter reported at 298 K as 5.4510 Å; 5.4507 Å at 293 K determined by graphical extrapolation.

DATA TABLE 320. THERMAL LINEAR EXPANSION OF GALLIUM PHOSPHIDE GaP

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		**CURVE 3**	
211	-0.053	298	0.006
297	0.002	418	0.075
373	0.042	550	0.150
473	0.099	681	0.215
		799	0.292
CURVE 2		912	0.387
0	-0.068		
300	0.002		
400	[illegible]		
500	.[illegible]1		
600	155		
800	.270		

DATA TABLE 320. COEFFICIENT OF THERMAL LINEAR EXPANSION OF GALLIUM PHOSPHIDE GaP

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 2	
0	0.00
300	4.65
400	4.97
500	5.27
600	5.52
800	5.97

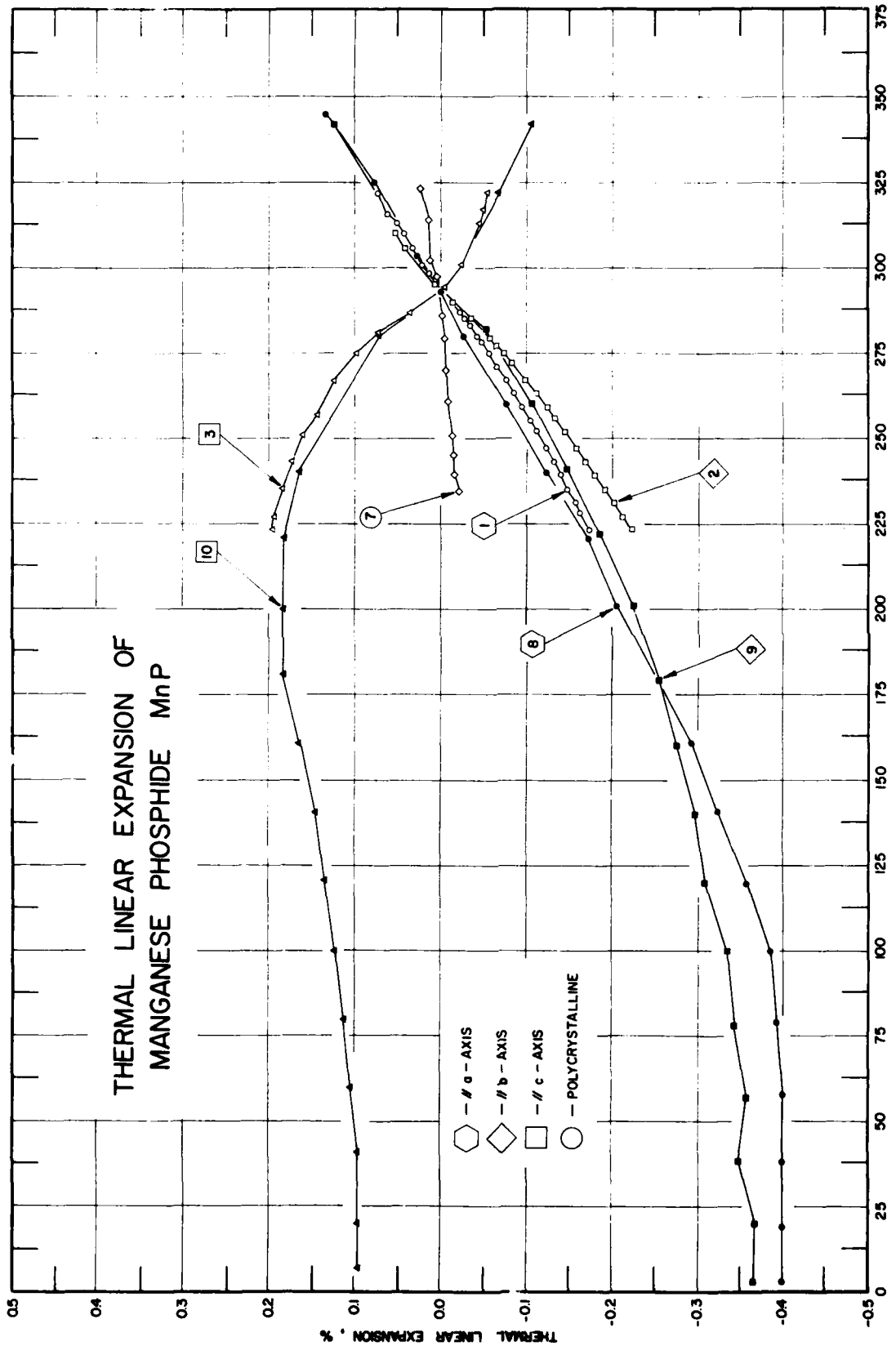

THERMAL LINEAR EXPANSION OF
MANGANESE PHOSPHIDE MnP
// a - AXIS
// b - AXIS
// c - AXIS
POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
1
2
3
7
8
9
10

FIGURE 321

SPECIFICATION TABLE 321. THERMAL LINEAR EXPANSION OF MANGANESE PHOSPHIDE MnP

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	863	Okamoto, T., Kamigaichi, T., Iwata, N., and Tatsumoto, E.	1968	S	223-322		99.99 pure single crystal; expansion measured along a-axis around the Curie point; zero-point correction is -0.173% at 293 K.
2	863	Okamoto, T., et al.	1968	S	223-310		The above specimen; expansion measured along b-axis around the Curie point; zero-point correction is -0.222% at 293 K.
3	863	Okamoto, T., et al.	1968	S	223-322		The above specimen; expansion measured along c-axis around the Curie point; zero-point correction is 0.197% at 223 K.
4*	863	Okamoto, T., et al.	1968	S	4-77		The above specimen; expansion measured along a-axis around the screw ferromagnetic transition temperature; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
5*	863	Okamoto, T., et al.	1968	S	4-77		The above specimen; expansion measured along b-axis around the screw ferromagnetic transition temperature; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
6*	863	Okamoto, T., et al.	1968	S	4-77		The above specimen; expansion measured along c-axis around the screw ferromagnetic transition temperature; this curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.
7	864	Grazhdankina, N.P., Barkhanov, A.M., and Bersenev, Yu.S.	1969	S	234-323		Zero-point correction is -0.0225% at 293 K.
8	865	Iwata, N.	1969	S	3-345		Cubic specimen; 7 x 7 x 7 mm; made from 99.99% pure Mn, 99.99% pure P, combined in evacuated quartz tube 10 mm ID x 150 mm long; heated at 773 K for several hr in furnace; 40 mm diameter x 250 mm long; held at 1473 K for 5 days, then cooled to yield polycrystalline MnP 10 mm diameter x 10 mm long; single crystal obtained by moving specimen vertically down at 3 mm/hr at 1473 K; dimension of single crystal was 10 mm diameter x 30 mm long; from this piece the final dimensions of the cube were obtained; faces of cube are within 2° of principle axes; expansion measured along a-axis; zero-point correction is 0.022% at 293 K; coefficient of thermal linear expansion also reported from 223 K to 309 K.
9	865	Iwata, N.	1969	S	3-342		The above specimen; expansion measured along b-axis; zero-point correction is 0.22% at 293 K; coefficient of thermal linear expansion also reported from 223 K to 321 K.
10	865	Iwata, N.	1969	S	7-342		The above specimen; expansion measured along c-axis; zero-point correction is -0.038% at 293 K; coefficient of thermal linear expansion also reported from 223 K to 321 K.

* Not shown in figure.

DATA TABLE 321. THERMAL LINEAR EXPANSION OF MANGANESE PHOSPHIDE MnP

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, -]

T	$\Delta L/L_0$
CURVE 1‡	
223	-0.173
228	-0.163
231	-0.157
235	-0.148
239	-0.140
243	-0.131
247	-0.122
252	-0.111
255	-0.104
259	-0.095*
263	-0.085
267	-0.076*
271	-0.065
275	-0.055*
278	-0.047
280	-0.041*
283	-0.033
285	-0.027*
287	-0.021*
289	-0.013
291	-0.006*
294	0.003
296	0.009*
298	0.014*
301	0.022
306	0.034*
310	0.044
313	0.052*
318	0.064
322	0.073
CURVE 2‡	
223	-0.222
227	-0.212
231	-0.201
235	-0.191*
239	-0.180
243	-0.169*
247	-0.158
252	-0.144*
256	-0.132
259	-0.124*
263	-0.111
267	-0.099*

T	$\Delta L/L_0$
CURVE 2 (cont.)‡	
272	-0.082
275	-0.072*
277	-0.065
279	-0.058*
281	-0.051
283	-0.043*
285	-0.035
287	-0.032*
289	-0.018*
290	-0.012
291	-0.008*
294	0.004*
295	0.008
297	0.015*
301	0.027*
306	0.042
310	0.053
CURVE 3‡	
223	0.197
227	0.193
231	0.189*
235	0.184
239	0.180*
243	0.174
247	0.168*
251	0.161
255	0.154*
259	0.145
263	0.136*
267	0.125
271	0.113*
275	0.099
277	0.092*
279	0.083*
281	0.074
283	0.063*
285	0.052*
287	0.038
289	0.021*
290	0.012*
291	0.007*
294	-0.004
295	-0.007*

T	$\Delta L/L_0$
CURVE 3 (cont.)‡	
297	-0.013*
301	-0.023
306	-0.033*
309	-0.034*
313	-0.044
318	-0.049
322	-0.052
CURVE 4*,§	
4.7	0.000×10^{-1}
6.5	0.000
8.6	-0.009
10.2	-0.018
12.2	-0.030
14.3	-0.042
17.5	-0.056
19.4	-0.069
21.8	-0.072
24.5	-0.082
27.1	-0.093
29.5	-0.100
32.2	-0.105
34.0	-0.114
36.3	-0.119
38.4	-0.126
40.2	-0.131
42.0	-0.134
44.0	-0.138
46.1	-0.198
48.5	-0.202
50.9	-0.199
52.9	-0.199
55.1	-0.198
56.8	-0.196
58.8	-0.196
61.2	-0.199
63.0	-0.199
66.1	-0.199
68.6	-0.199
70.6	-0.199
74.2	-0.199
77.3	-0.198

T	$\Delta L/L_0$
CURVE 5*,§	
4.7	0.001×10^{-1}
6.7	0.003
9.3	0.005
11.5	0.005
13.4	0.007
16.3	0.007
18.8	0.007
21.0	0.007
23.3	0.009
26.2	0.009
28.1	0.010
30.4	0.010
32.8	0.013
35.0	0.013
37.3	0.013
40.1	0.015
42.0	0.015
44.2	0.015
45.2	0.035
47.2	0.035
49.3	0.035
51.7	0.038
53.8	0.045
55.9	0.049
57.9	0.056
59.8	0.058
62.1	0.064
64.5	0.068
66.4	0.072
68.5	0.079
70.3	0.084
74.2	0.091
77.3	0.095
CURVE 6*,§	
4.9	0.003×10^{-1}
6.8	0.009
8.8	0.027
10.8	0.032
13.4	0.041
16.0	0.038
18.3	0.035
21.5	0.027
25.5	0.016

T	$\Delta L/L_0$
CURVE 6 (cont.)*,§	
28.1	0.015×10^{-1}
31.5	0.006
34.0	0.003
36.2	0.003
38.3	0.000
40.0	0.000
41.9	0.000
45.0	0.000
45.6	0.054
48.5	0.060
50.5	0.063
52.5	0.067
55.5	0.070
58.6	0.076
60.5	0.078
63.3	0.084
65.2	0.088
67.2	0.092
70.3	0.101
74.1	0.109
77.1	0.115
CURVE 7	
234	-0.021
235	-0.019*
239	-0.018
242	-0.016*
245	-0.015
248	-0.013*
251	-0.013
254	-0.012*
258	-0.010*
261	-0.009
264	-0.008*
267	-0.007*
270	-0.006
273	-0.005*
276	-0.004*
279	-0.004
281	-0.003*
284	-0.002*
286	-0.001
288	-0.001*
291	-0.001*

T	$\Delta L/L_0$
CURVE 7 (cont.)	
293	0.000*
294	0.001*
296	0.002*
297	0.003
299	0.003*
301	0.004*
302	0.006
305	0.008*
308	0.011*
314	0.015
319	0.020*
323	0.025
CURVE 8	
3	-0.400
19	-0.400
38	-0.400
58	-0.400
79	-0.394
100	-0.387
120	-0.357
141	-0.324
161	-0.291
201	-0.207
221	-0.171
240	-0.121
260	-0.076
280	-0.026
293	0.000
303	0.029
325	0.079
345	0.133
CURVE 9	
3	-0.365
20	-0.368
38	-0.349
57	-0.358
78	-0.342
100	-0.334
120	-0.309
140	-0.296
160	-0.275

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0 = 0$.
§ This curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 321. THERMAL LINEAR EXPANSION OF MANGANESE PHOSPHIDE MnP (continued)

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 9 (cont.)		CURVE 9 (cont.)		CURVE 10		CURVE 10 (cont.)		CURVE 10 (cont.)		CURVE 10 (cont.)	
179	-0.254	282	-0.051	7	0.096	100	0.122	200	0.181	293	0.000*
201	-0.227	293	0.000*	20	0.097	121	0.135	221	0.181	322	-0.066
222	-0.186	322	0.075*	41	0.096	141	0.148	240	0.165	342	-0.105
241	-0.148	342	0.124	60	0.106	161	0.163	260	0.134		
260	-0.108			80	0.111	181	0.181	280	0.074*		

DATA TABLE 321. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MANGANESE PHOSPHIDE MnP

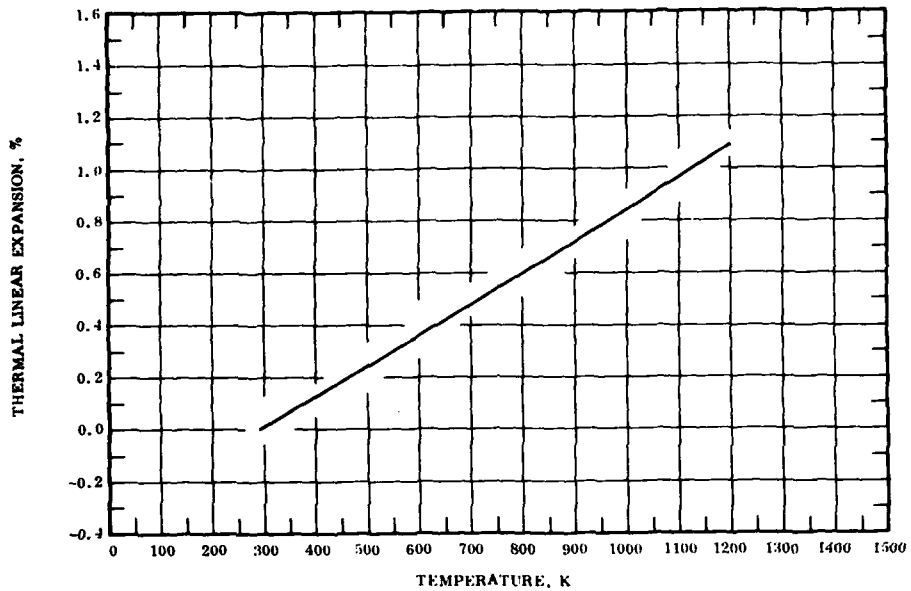
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α	T	α	T	α
CURVE 1‡		CURVE 2‡		CURVE 3 (cont.)‡		CURVE 8		CURVE 9 (cont.)		CURVE 10 (cont.)	
223	20.4	223	25.7	227	-10.3	223	20.9	231	25.9	227	-9.5
228	20.4*	227	25.7	231	-10.3	228	20.9	234	25.9	231	-9.5
231	20.6*	231	26.5	235	-11.9	231	20.9	239	26.8	235	-10.1
235	21.5	235	26.5	239	-13.1	235	20.9	243	27.8	239	-12.3
239	21.5*	239	26.7	243	-14.0	239	20.9	247	27.8	243	-13.8
243	21.5*	243	27.3	247	-16.1	243	20.9	251	27.8	246	-15.1
247	22.1*	247	28.3	251	-18.5	247	22.0	255	28.7	251	-16.7
252	22.9*	252	28.8	255	-19.2	251	22.0	258	30.0	255	-19.3
255	22.9*	256	28.8	259	-22.3	255	22.7	263	30.9	259	-21.1
259	23.8	259	30.3	263	-25.1	259	23.5	266	32.1	263	-24.4
263	24.2*	263	31.2	267	-28.0	263	24.0	271	32.9	267	-27.2
267	24.7*	267	31.6	271	-32.2	266	24.9	275	34.5	271	-31.4
271	25.9*	272	33.0	275	-37.0	271	25.6	277	34.5	275	-35.6
275	26.9	275	34.8	277	-40.2	275	27.3	280	36.2	277	-39.2
278	27.2*	277	35.4	279	-44.5	277	27.3	283	38.1	279	-43.3
280	27.2*	279	36.8	281	-50.2	279	27.3	285	39.7	280	-48.5
283	29.1*	281	37.1	283	-54.0	283	29.1	287	42.9	283	-53.8
285	30.3	283	38.1	285	-62.1	285	30.9	289	48.4	285	-61.0
287	33.0*	285	39.9	287	-74.4	287	33.3	290	53.1	287	-73.7
289	37.8	287	43.7	289	-97.4	288	37.8	291	44.1	289	-96.8
291	35.8	289	49.0	290	-73.8	290	41.0	293	33.8	290	-72.3
294	27.3	290	55.3	291	-37.9	291	36.1	295	32.4	291	-38.1
296	26.2*	291	44.0	294	-33.7	293	27.5	297	32.0	293	-34.3
298	26.2	294	36.0	295	-29.5	295	26.1	300	30.4*	295	-29.0
302	25.0*	295	33.7	297	-27.2	297	26.3	305	27.7*	297	-26.3
306	25.0*	297	32.1	301	-22.4*	300	26.3*	309	26.3*	301	-22.2*
310	25.0*	301	30.3*	306	-19.2*	305	25.4*	313	23.9*	305	-18.3*
313	24.2*	306	28.8*	309	-15.9*	309	24.3*	317	23.3*	309	-15.4*
318	24.2*	310	26.9*	313	-12.9*			321	23.3*	313	-12.8*
322	24.2*			318	-8.0*	CURVE 9				317	-8.2*
		CURVE 3‡		322	-5.9*			CURVE 10		321	-6.1*
		223	-9.2			223	25.9				
						227	25.9	223	-9.5		

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0 = 0$.

FIGURE AND TABLE NO. 322R. RECOMMENDED THERMAL LINEAR EXPANSION OF PLUTONIUM PHOSPHIDE PuP



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	11.6
300	0.008	11.6
400	0.125	11.7
500	0.242	11.8
600	0.360	11.9
700	0.479	11.9
800	0.599	12.0
900	0.720	12.1
1000	0.841	12.2
1100	0.963	12.3
1200	1.086	12.4
1250	1.147	12.4

REMARKS

The recommended values are based on the data for high-purity samples. These values are considered accurate to within ±5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.337 + 1.137 \times 10^{-3}\, T + 4.056 \times 10^{-6}\, T^2 - 3.266 \times 10^{-13}\, T^3$$

The tabulated values for the coefficient of thermal expansion are calculated by differentiating the above equation and are considered accurate to about ±10%.

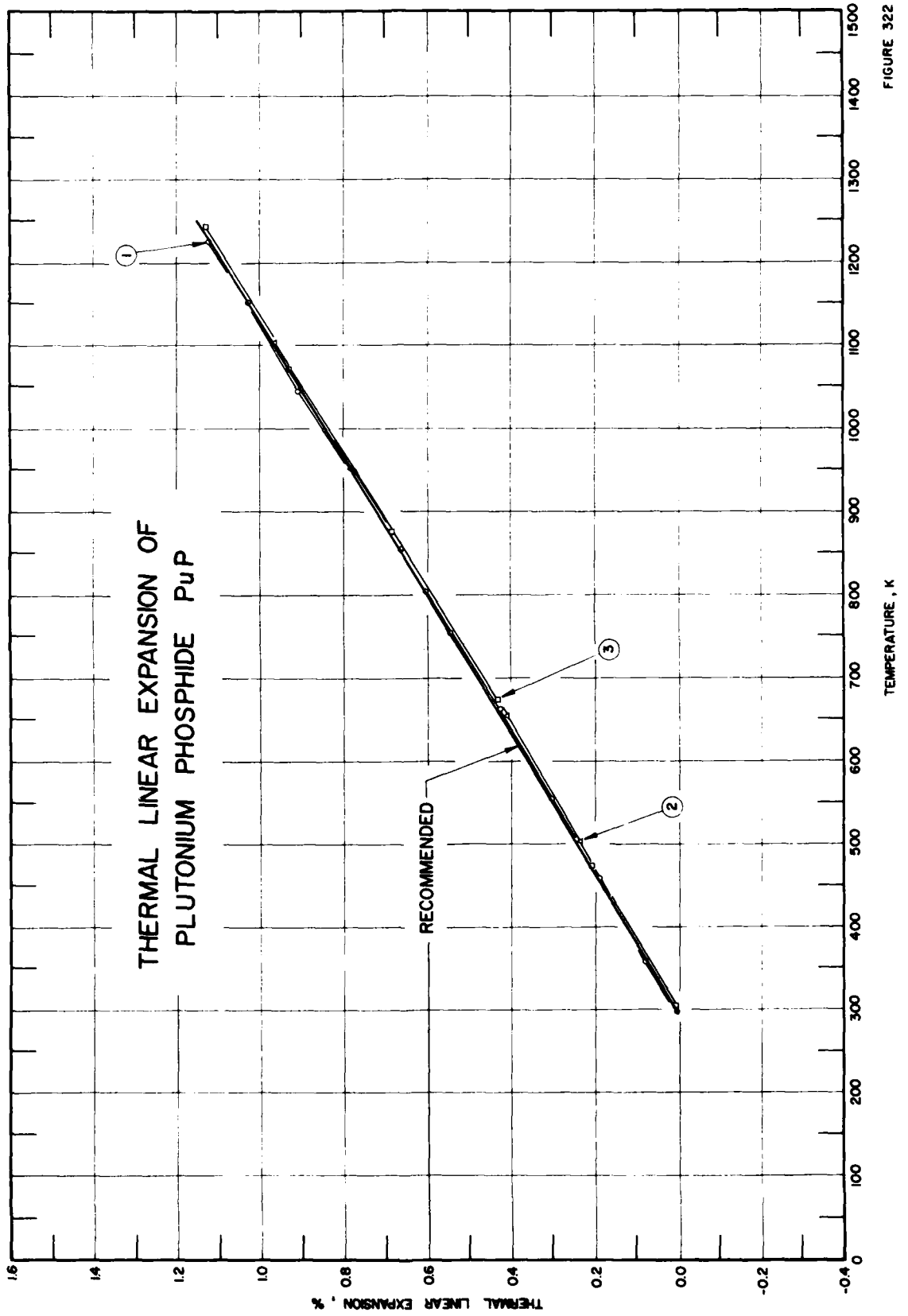

THERMAL LINEAR EXPANSION OF
PLUTONIUM PHOSPHIDE PuP
RECOMMENDED
1
2
3
THERMAL LINEAR EXPANSION , %
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
TEMPERATURE , K
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 322

SPECIFICATION TABLE 322. THERMAL LINEAR EXPANSION OF PLUTONIUM PHOSPHIDE PuP

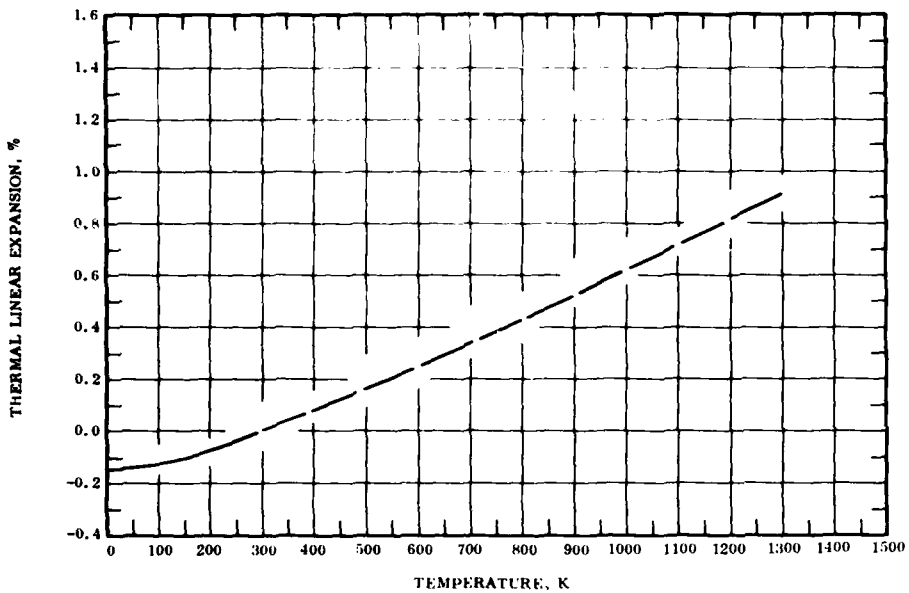
Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	866	Kruger, O. L. and Moser, J. B.	1966	L	297-1225		Starting material 99.97 pure plutonium with 0.013 impurities; specimen 0.7 cm diameter and 1.3 cm long pellet; PuP prepared by high-temperature homogenization of the product from the reaction of PH_3 gas with partly decomposed plutonium hydride prepared by reaction of plutonium with flowing high purity hydrogen at 473 K; formed at 21.1 kg mm^{-2} and heated at 273 K for 2 hr; all operation carried out in an inert atmosphere of high-purity nitrogen gas; measured with increasing temperature; zero-point correction is 0.005% at 293 K.
2	866	Kruger, O. L. and Moser, J. B.	1966	L	1102-502		The above specimen measured with decreasing temperature.
3	137	Kruger, O. L. and Moser, J. B.	1965	L	302-1243		Zero-point correction is -0.01% at 293 K.

DATA TABLE 322. THERMAL LINEAR EXPANSION OF PLUTONIUM PHOSPHIDE PuP

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 3	
297	0.005	302	0.010
357	0.080	473	0.208
457	0.192	673	0.434
553	0.306	875	0.683
661	0.428	1072	0.928
753	0.547	1243	1.133
803	0.605		
854	0.663		
1046	0.907		
1152	1.033		
1225	1.133		
CURVE 2			
1102	0.967		
952	0.782		
653	0.416		
502	0.239		

FIGURE AND TABLE NO. 323 C. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF URANIUM PHOSPHIDE UP



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
5	-0.150	-1.8
25	-0.153	-0.2
50	-0.151	1.5
75	-0.145	3.1
100	-0.136	4.4
150	-0.108	6.5
200	-0.072	7.6
250	-0.033	7.7
293	0.000	7.8
300	0.005†	7.8†
400	0.083†	8.0†
500	0.165†	8.4†
600	0.251†	8.7†
700	0.340†	9.0†
800	0.432†	9.3†
900	0.526†	9.5†
1000	0.621†	9.6†
1100	0.718†	9.7†
1200	0.815†	9.7†
1300	0.912†	9.8†

† Provisional values.

REMARKS

The recommended values are considered to about ± 5% at temperatures below 293 K and ± 10% above 293 K. These values are represented by the following equations:

$$\Delta L/L_0 = -0.150 - 2.252 \times 10^{-4}\, T + 4.232 \times 10^{-6}\, T^2 - 5.879 \times 10^{-9}\, T^3 \qquad (5\text{-}293\ K)$$

$$\Delta L/L_0 = -0.199 + 5.938 \times 10^{-4}\, T + 3.104 \times 10^{-7}\, T^2 - 8.462 \times 10^{-11}\, T^3 \qquad (293\text{-}1300\ K)$$

The tabulated values for the coefficient of thermal expansion are derived primarily by differentiating the above equation and are considered accurate to about ±10%.

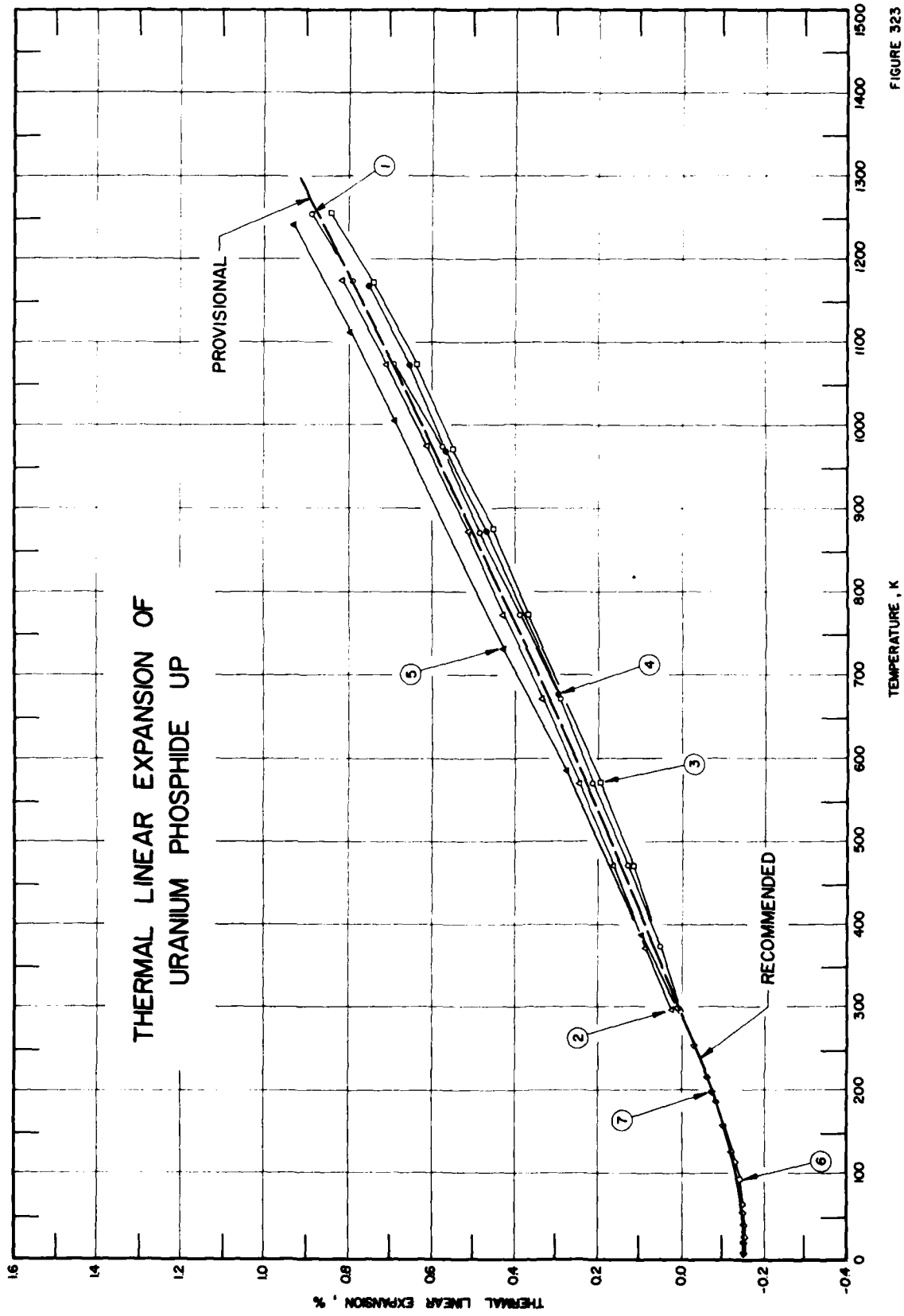

THERMAL LINEAR EXPANSION OF
URANIUM PHOSPHIDE UP
PROVISIONAL
RECOMMENDED
1
2
3
4
5
6
7
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 323

SPECIFICATION TABLE 323. THERMAL LINEAR EXPANSION OF URANIUM PHOSPHIDE UP

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	867	Baskin, Y.	1966	L	297-1258		88.45 U, 11.37 P, and 0.18 O; dimension: 2.54 cm long; homogenized material crushed by mortar and pestle to pass a 200 mesh screen; ball-milling for 5 hr in plastic jars using stainless steel ball, reduced the average particle size from 2.5 to 2.0 μm; all screening and fabrication operations performed in argon-atom; pellet prepared in a steel die 0.67 cm in diameter at pressure between 20,000 40,000 psi; sintered in vacuum at 1873 to 2273 K; sintered densities from 8.0 g cm^{-3} to 9.9 g cm^{-3}; measured in vacuum; apparatus calibrated with Armco iron and copper; measured with increasing temperature; zero-point correction is -0.002%; reported error ±0.05%.
2	867	Baskin, Y.	1966	L	1177-297		The above specimen except measured with decreasing temperature; zero-point correction -0.003% at 293 K.
3	868	Baskin, Y.	1965	L	373-1257		Expansion measured with increasing temperature.
4	868	Baskin, Y.	1965	L	1170-373		Expansion measured with decreasing temperature.
5	713	Street, R.S. and Rand, M.H.	1969	X	293-1243		Specimen prepared by vacuum decomposition of U_3P_4 at 1573 K; specimen contained ~5.0 percent UO_2; x-ray analysis detected UP only in face-centered-cubic structure; lattice parameter reported at 293 K as 5.5886 Å.
6	854	Marples, J.A.C.	1969	X	4-300		99.79 UP, 0.210, 0.003 metallic impurities; faint trace UO_2 powder; glued to 2 mm thick metal plate with shellac; lattice parameter reported at 293 K as 5.58802 Å.
7	843	Lander, G.H. and Mueller, M.H.	1974	X	200-300		Particle size ~40 μm crystal structure of NaCl; powder was depressed at 527 kg/cm^2 into flat disk; placed in milled recess in copper sample holder; disk covered with 0.005 cm Mylar window sealed with copper frame and resin; lattice parameter reported at 300 K as 5.589 Å.

DATA TABLE 323. THERMAL LINEAR EXPANSION OF URANIUM PHOSPHIDE UP

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
297	0.002
373	0.056
473	0.127
573	0.216
673	0.292
773	0.388
874	0.483
978	0.576
1078	0.692
1175	0.791
1258	0.886
CURVE 2	
1177	0.816
1076	0.714
977	0.613
874	0.515
774	0.427
673	0.335
573	0.243
473	0.161
372	0.085
297	0.026
CURVE 3	
373	0.044*
472	0.115
573	0.194
673	0.286*
774	0.369
877	0.453
972	0.551
1075	0.638
1172	0.741
1257	0.840
CURVE 4	
1170	0.752
1074	0.651
971	0.563
874	0.466
774	0.384*
675	0.298
CURVE 4 (cont.)	
572	0.210*
472	0.128*
373	0.057*
CURVE 5	
293	0.000*
388	0.089
588	0.277
733	0.425
1009	0.685
1114	0.797
1243	0.930
CURVE 6	
4.7	-0.152
20.0	-0.154
26.9	-0.158
40.0	-0.156
54.1	-0.154
64.1	-0.151
79.0	-0.147*
95.5	-0.142
109.5	-0.131*
117.4	-0.128
127.9	-0.122
159.0	-0.102
188.9	-0.083
218.7	-0.063
255.9	-0.031
293.0	0.000*
300.0	0.006
CURVE 7	
200	-0.0753
293	0.000
300	0.005

* Not shown in figure.

SPECIFICATION TABLE 324. THERMAL LINEAR EXPANSION OF MISCELLANEOUS PHOSPHIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	861	Kudman, I. and Paff, P.J.	1972	X	298-909	$In_{0.217}Ga_{1.783}P$	Indium gallium phosphide; specimen made by grinding to pass through 500 mesh screen; loaded into 0.30 mm ID quartz capillaries and sealed; lattice parameter reported at 298 K as 5.5421 Å; 5.5418 Å at 293 K determined by graphical extrapolation.
2*	861	Kudman, I. and Paff, P.J.	1972	X	290-848	$In_{0.447}Ga_{0.553}P$	Indium gallium phosphide; similar to the above specimen except different composition; lattice parameter reported at 290 K as 5.6383 Å; 5.6384 Å at 293 K determined by graphical interpolation.
3*	861	Kudman, I. and Paff, P.J.	1972	X	291-911	$In_{0.784}Ga_{0.553}P$	Indium gallium phosphide; similar to the above specimen except different composition; lattice parameter reported at 291 K as 5.7705 Å; 5.7705 Å at 293 K determined by graphical interpolation.
4*	861	Kudman, I. and Paff, P.J.	1972	X	289-912	InP	Indium phosphide; similar to the above specimen except different composition; lattice parameter reported at 289 K as 5.8697 Å; 5.8698 Å at 293 K determined by graphical interpolation.
5*	862	Fasiska, E.J. and Zwell, L.	1967	X	296-951	Fe_3P	Iron phosphide; 99.5+ pure, material prepared by melting under vacuum commercially pure iron and ferrophosphor, then crushed for analysis; expansion of crystal a-axis measured; lattice parameter reported at 296 K as 9.100 Å; 9.099 Å at 293 K determined by graphical extrapolation.
6*	862	Fasiska, E.J. and Zwell, L.	1967	X	296-951	Fe_3P	Iron phosphide; the above specimen except expansion of crystal c-axis measured; lattice parameter reported at 296 K as 4.459 Å; 4.458 Å at 293 K determined by graphical extrapolation.
7*	843	Lander, G.H. and Mueller, M.H.	1974	L	200-300	NpP	Neptunium phosphide; particle size ~ 40 μm crystal structure of NaCl; powder was depressed at 527 kg/cm^2 into flat disk placed in milled recess in copper sample holder; disk covered with 0.005 cm Mylar window sealed with copper frame and resin; lattice parameter reported at 300 K as 5.615 Å.
8*	172	Aronson, S., Cisney, E., and Gingerich, K.A.	1967	X	293-1907	$ThP_{0.71}$	Thorium phosphide; sample prepared by heat-treating mixtures of Th_3P_4 and thorium metal powder; CuKα radiation; (531), (600), (620), and (533) lines used; melting point 3173 K; lattice parameter reported at 293 K as 5.833 Å.
9*	172	Aronson, S., et al.	1967	X	293-2017	$ThP_{0.91}$	Thorium phosphide; similar to the above except (440), (531), and (600) lines used; lattice parameter reported at 293 K as 5.836 Å.
10*	172	Aronson, S., et al.	1967	X	293-1433	Th_3P_4	Thorium phosphide; prepared by the conventional Faraday method; CuKα radiation; (653), (750), (761), and (745) lines used.

* No figure given.

DATA TABLE 324. THERMAL LINEAR EXPANSION OF MISCELLANEOUS PHOSPHIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
298	0.005
448	0.122
503	0.158
584	0.186
649	0.212
844	0.336
909	0.380
CURVE 2*	
290	-0.002
462	0.089
601	0.163
678	0.202
765	0.257
848	0.293
CURVE 3*	
291	0.000
432	0.045
590	0.147
671	0.182
748	0.218
843	0.255
911	0.314
CURVE 4*	
289	-0.002
336	0.027
380	0.046
490	0.111
624	0.174
703	0.208
788	0.242
816	0.259
912	0.295
CURVE 5*	
296	0.0033
687	0.410
951	0.817
CURVE 6*	
296	0.0090
687	1.063
951	1.579
CURVE 7*	
200	-0.089
293	0.000
300	0.006
CURVE 8*	
293	0.000
1201	0.637
1293	0.723
1359	0.773
1439	0.808
1489	0.876
1597	0.927
1705	1.014
1792	1.116
1907	1.202
CURVE 9*	
293	0.000
1196	0.659
1382	0.787
1583	0.921
1814	1.111
2017	1.270
CURVE 10*	
293	0.000
1135	0.571
1153	0.574
1274	0.669
1287	0.677
1407	0.777
1433	0.787

* No figure given.

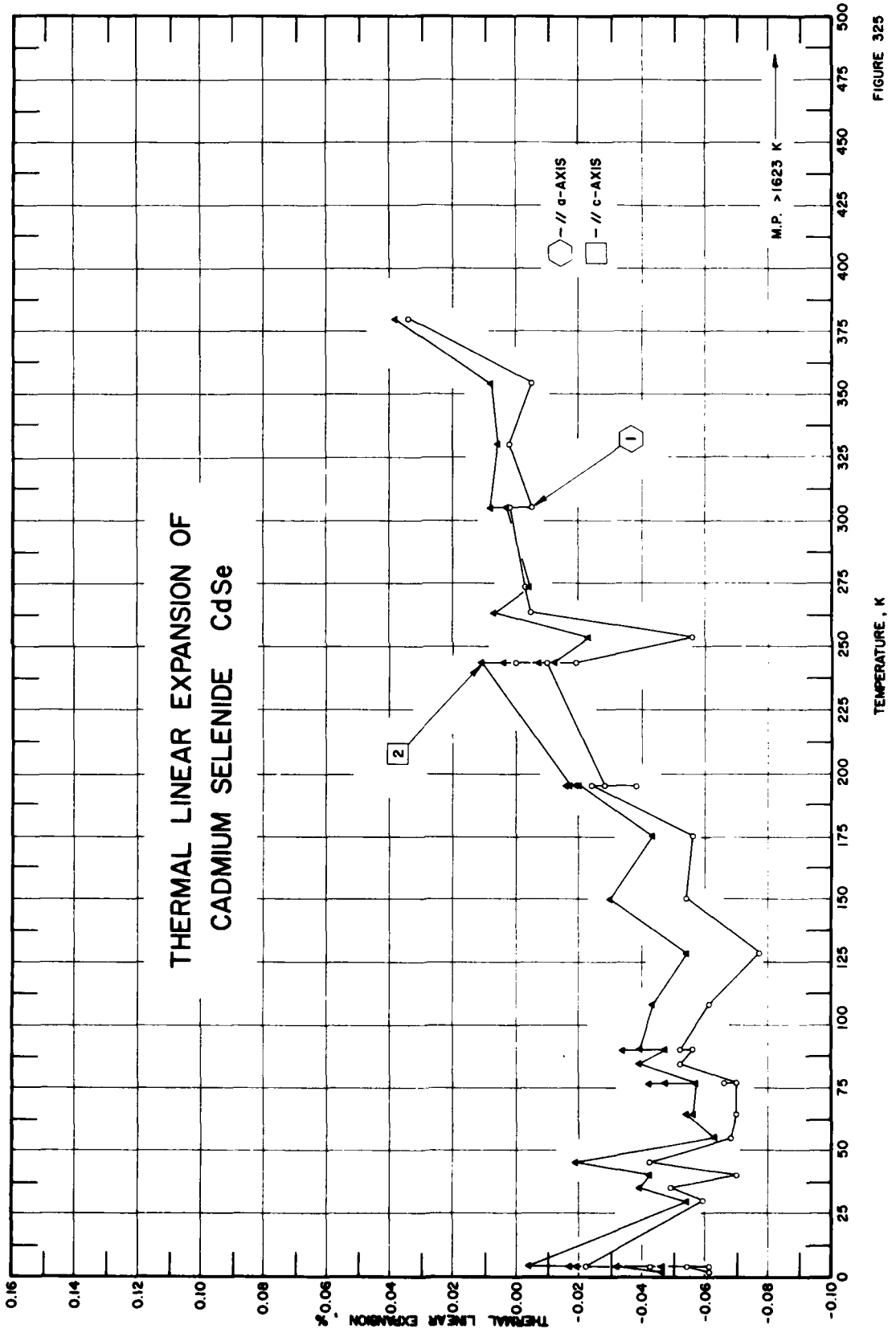

THERMAL LINEAR EXPANSION OF
CADMIUM SELENIDE CdSe
// a-AXIS
// c-AXIS
M.P. >1623 K
1
2
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500

FIGURE 325

SPECIFICATION TABLE 325. THERMAL LINEAR EXPANSION OF CADMIUM SELENIDE CdSe

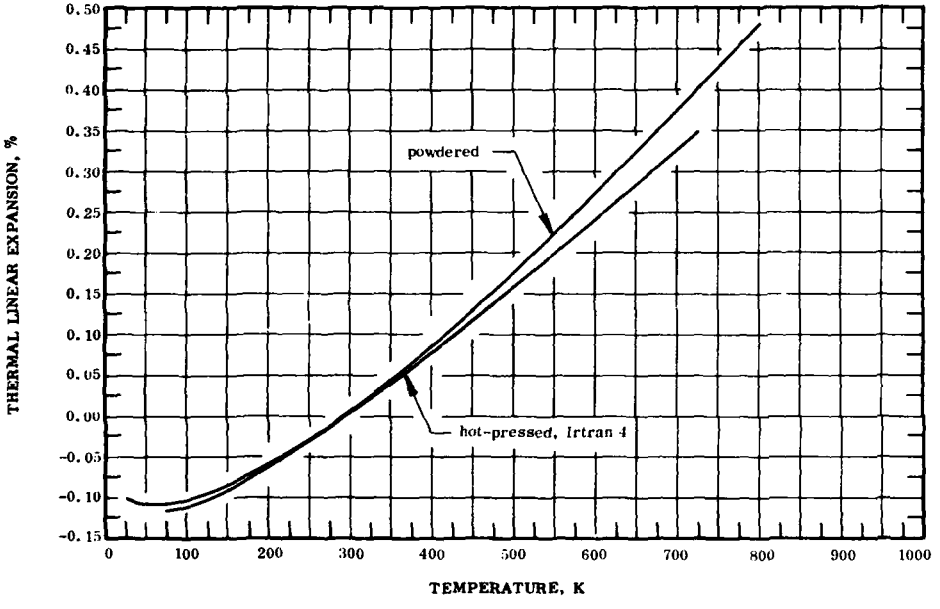
Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	869	Reeber, R.R.	1969	X	2-380		Eagle-Picher ultrapure 99.99+ grade, 0.0350 H, 0.0100 O; prepared by filling 1.27 cm I.D. clear fused silica capsules with as received material; expansion measured along a-axis; lattice parameter reported at 273 K as 4.3003 Å; 4.3004 Å at 293 K determined by graphical interpolation.
2	869	Reeber, R.R.	1969	X	2-380		The above specimen; expansion measured along c-axis; lattice parameter reported at 273 K as 7.0111 Å; 7.0108 Å at 293 K determined by graphical interpolation.

DATA TABLE 325. THERMAL LINEAR EXPANSION OF CADMIUM SELENIDE CdSe

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 1 (cont.)		CURVE 2 (cont.)		CURVE 2 (cont.)	
2	-0.061	90	-0.056	273	-0.003	45	-0.019	195	-0.016
4.2	-0.054	90	-0.052	305	0.002	55	-0.063	195	-0.017
4.2	-0.042	90	-0.056	305	-0.005	64	-0.054	243	0.011
4.2	-0.061	90	-0.052	330	0.002	64	-0.056	243	-0.007
4.2	-0.042	108	-0.061	354	-0.005	77	-0.057	243	0.004
4.2	-0.022	128	-0.077	380	0.034	77	-0.047	243	-0.012
30	-0.059	150	-0.054			77	-0.042	253	-0.023
35	-0.049	175	-0.056	CURVE 2		77	-0.057	263	0.007
40	-0.070	195	-0.024			84	-0.039	273	-0.004
45	-0.042	195	-0.038	2	-0.046	90	-0.047	305	0.003
55	-0.068	195	-0.028	4.2	-0.032	90	-0.034	305	0.008
64	-0.070	195	-0.028	4.2	-0.019	90	-0.039	330	0.006
64	-0.070	243	-0.010	4.2	-0.046	108	-0.043	354	0.008
77	-0.070	243	-0.019	4.2	-0.017	128	-0.054	380	0.038
77	-0.066	243	0.000	4.2	-0.004	150	-0.030		
77	-0.066	243	-0.019	30	-0.054	175	-0.043		
77	-0.070	253	-0.056	35	-0.039	195	-0.020		
84	-0.052	263	-0.005	40	-0.042	195	-0.019		

FIGURE AND TABLE NO. 326R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF ZINC SELENIDE ZnSe



RECOMMENDED VALUES

[*Temperature*, T, K; *Linear Expansion*, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Powdered		Hot-Pressed (Irtran 4)	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
25	-0.100	-2.1		
34	-0.105	-3.0		
50	-0.108	-1.3		
75	-0.108	1.0	-0.117	1.5
100	-0.104	2.6	-0.112	3.0
150	-0.084	4.6	-0.092	5.1
200	-0.059	5.8	-0.062	6.2
250	-0.029	6.6	-0.029	6.9
293	0.000	7.0	0.000	7.4
300	0.005	7.1	0.005	7.4
350	0.044	7.7	0.041	7.7
400	0.086	8.5	0.078	8.0
450	0.129	8.8	0.117	8.0
500	0.175	9.3	0.157	8.1
550	0.223	9.7	0.198	8.2
600	0.272	10.1	0.240	8.2
650	0.323	10.4	0.283	8.3
700	0.374	10.5	0.326	8.4
725	0.401	10.6	0.348	8.5
750	0.427	10.7		
775	0.454	10.8		
800	0.481	10.9		

REMARKS

The recommended values are considered to within ± 5% and are represented approximately by the following equations:

Powdered: $\Delta L/L_0 = -0.168 + 3.768 \times 10^{-4}\ T + 7.439 \times 10^{-7}\ T^2 - 2.503 \times 10^{-10}\ T^3$ (293-800 K)

Hot-Pressed (Irtran 4): $\Delta L/L_0 = -0.170 + 4.419 \times 10^{-4}\ T + 5.309 \times 10^{-7}\ T^2 - 2.158 \times 10^{-10}\ T^3$ (150-725 K)

The tabulated values of the coefficient of thermal expansion are primarily based on the selected experimental data and are considered accurate to about ± 7%.

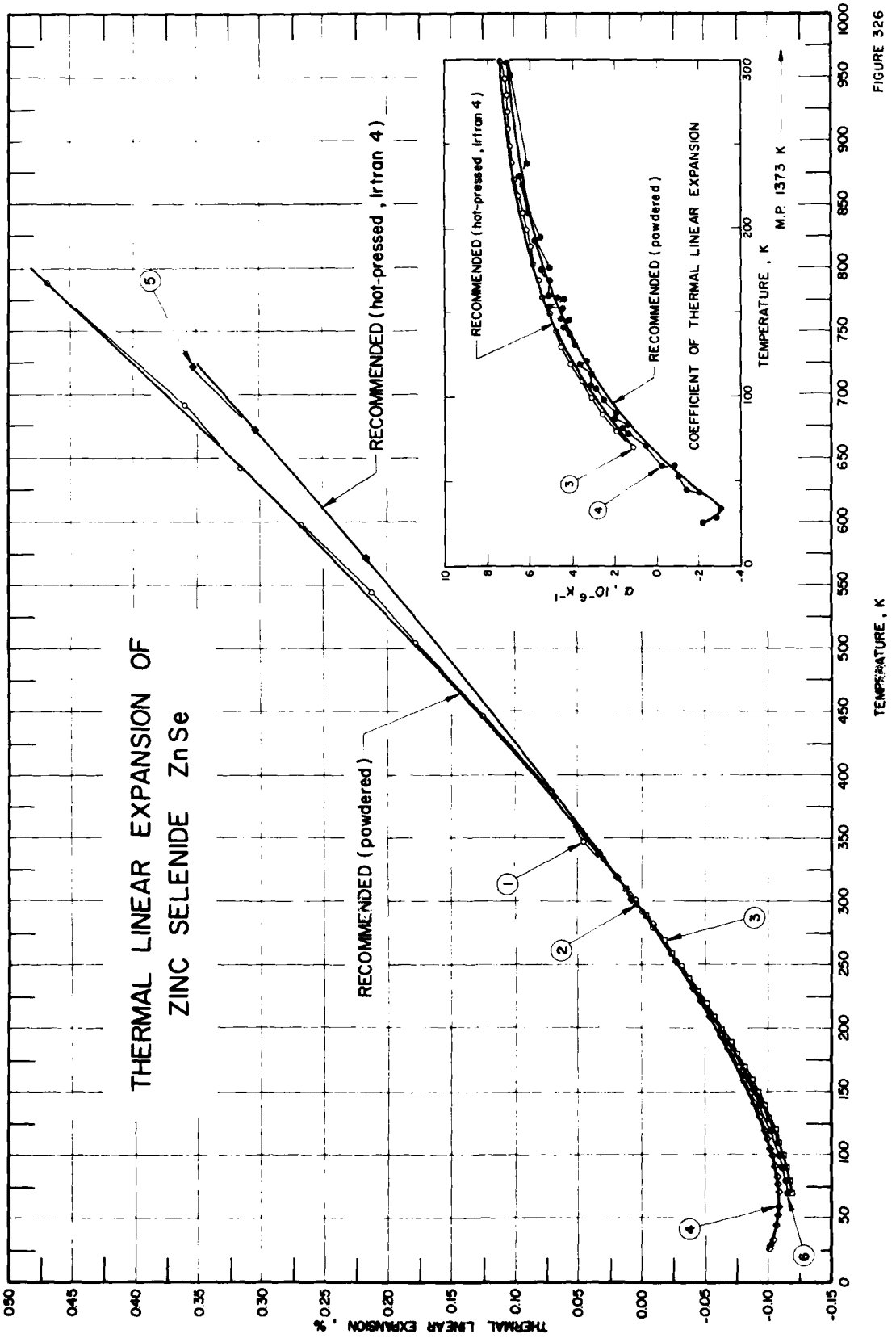

THERMAL LINEAR EXPANSION OF
ZINC SELENIDE ZnSe
RECOMMENDED (hot-pressed, Irtran 4)
RECOMMENDED (powdered)
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
M.P. 1373 K
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED (hot-pressed, Irtran 4)
RECOMMENDED (powdered)
α, 10⁻⁶ K⁻¹
TEMPERATURE, K

FIGURE 326

SPECIFICATION TABLE 326. THERMAL LINEAR EXPANSION OF ZINC SELENIDE ZnSe

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	874	Singh, H. P. and Dayal, B.	1967	X	293-790		Specimen in powder form; lattice parameter reported at 293 K as 5.6689 Å.
2	148	Ballard, S.S. and Browder, J.S.	1966	I	298-333	Irtran 4	Infrared optical material, microcrystalline, hot pressed compact developed by Eastman Kodak Company of New York; useful transmittance at 25 C; 0.5 to 22 μ, density 5.27 g/cc; reported error <2%.
3	149	Browder, Y.S. and Ballard, S.S.	1969	L/E	70-310	Irtran 4	Microcrystalline, hot-pressed compact developed by the Eastman Kodak Co. of Rochester, N.Y.
4	463	Novikova, S.I.	1961	L	26-339		Specimen smelted from 99.9996 pure Zn and 99.992 Se; compressed in atmosphere of nitrogen into cylinder 4.78 mm long; annealed at 1350 C; data reported is the average of six series of measurements.
5	875	Ladd, L.S., Clark, R., and Roy, D.	1964		303-723		Hot pressed; density 5.267 g cm^{-3}.
6	327	Browder, J.S.	1967	L	70-310	Irtran 4	Polycrystalline material, artificial produced infrared-transmitting optical, developed by Eastman Kodak Co.; specimen 0.250 in. diameter, 0.500 in. long, right cylinder, polished opposite ends parallel to within 0.0001 in.; reported error ± 5%.

DATA TABLE 326. THERMAL LINEAR EXPANSION OF ZINC SELENIDE ZnSe

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
302	0.005
348	0.046
388	0.071
447	0.125
505	0.178
545	0.212
599	0.268
643	0.316
692	0.360
790	0.469
CURVE 2	
298	0.0038
333	0.0301
CURVE 3‡	
70	-0.119
80	-0.118
90	-0.115
100	-0.113
110	-0.109
120	-0.106
130	-0.101
140	-0.097
150	-0.092
160	-0.087
170	-0.081
180	-0.075
190	-0.070
200	-0.063
210	-0.057
220	-0.051
230	-0.044
240	-0.037
250	-0.031
260	-0.024
270	-0.017
280	-0.009
290	-0.002
300	0.005*
310	0.013

T	$\Delta L/L_0$
CURVE 4‡	
26	-0.102
29	-0.103
34	-0.105
44	-0.107*
45	-0.107*
53	-0.108
60	-0.109
60	-0.109*
71	-0.109*
78	-0.108*
80	-0.108
82	-0.108*
83	-0.108
84	-0.107*
88	-0.107*
91	-0.106
91	-0.106*
98	-0.105*
99	-0.104*
100	-0.104
106	-0.102*
107	-0.102*
108	-0.102*
114	-0.100
114	-0.100*
116	-0.099*
120	-0.098
122	-0.097*
122	-0.097*
131	-0.094
133	-0.093*
138	-0.091*
138	-0.091*
142	-0.089
145	-0.088*
147	-0.087*
147	-0.087*
150	-0.086
153	-0.085*
154	-0.084*
159	-0.082*
160	-0.081
161	-0.081*
163	-0.080*

T	$\Delta L/L_0$
CURVE 4 (cont.)‡	
169	-0.077
169	-0.077*
174	-0.074*
177	-0.073*
178	-0.072*
185	-0.068*
189	-0.066
193	-0.064*
195	-0.063
201	-0.059*
207	-0.056*
210	-0.054
219	-0.049*
222	-0.047
227	-0.044*
232	-0.041*
237	-0.037*
239	-0.036
253	-0.027*
269	-0.017*
282	-0.008
292	-0.001*
299	0.004*
306	0.009*
313	0.014
320	0.019
339	0.033
CURVE 5	
303	0.008
573	0.216
673	0.304
723	0.353
CURVE 6‡	
70	-0.116
80	-0.115*
90	-0.113*
100	-0.110*
110	-0.107
120	-0.103*
130	-0.099

T	$\Delta L/L_0$
CURVE 6 (cont.)‡	
140	-0.094*
150	-0.089*
160	-0.084*
170	-0.078*
180	-0.074*
190	-0.070*
200	-0.064*
210	-0.057*
310	0.012*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 326. COEFFICIENT OF THERMAL LINEAR EXPANSION OF ZINC SELENIDE ZnSe

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3‡	
70	1.12
80	1.81
90	2.46
100	3.07
110	3.58
120	4.04
130	4.46
140	4.77
150	5.08
160	5.37
170	5.58
180	5.79
190	5.99
200	6.17
210	6.30
220	6.50
230	6.70
240	6.80
250	6.90
260	7.00
270	7.10
280	7.20
290	7.30
300	7.40
310	7.50*
CURVE 4‡	
26	-2.24
29	-2.84
34	-3.05
44	-2.18
45	-1.52
53	-1.09
60	-0.90
60	-0.20
71	0.50
78	1.34
80	1.34*
82	1.66
83	1.53
84	1.60*
88	2.00
91	1.90
91	2.08*
CURVE 4 (cont.)‡	
98	2.50
99	2.43*
100	2.56*
106	2.87
107	3.04
108	2.99*
114	3.03*
114	3.12
116	3.22*
120	3.64
122	3.36
122	3.61*
131	3.92
133	4.04*
138	4.05
138	4.34*
142	4.35
145	4.43*
147	4.19
147	4.56
150	4.47*
153	4.41
154	5.08
159	4.39
160	4.60
161	5.28
163	4.60*
169	5.12
169	5.40*
174	4.97*
177	5.40
178	5.13
185	5.39*
189	5.47*
193	5.72
195	5.59
201	5.93*
207	5.95*
210	6.00
219	6.05*
222	6.20*
227	6.30
232	6.50
237	6.41*
239	6.14
CURVE 4 (cont.)‡	
253	6.48*
269	6.72*
282	6.91*
292	6.98
299	7.05
306	6.97*
313	7.00*
320	7.32*
339	7.29*
CURVE 6*,‡	
70	1.17
80	1.81
90	2.46
100	3.07
110	3.58
120	4.04
130	4.46
140	4.77
150	5.08
160	5.37
170	5.58
180	5.78
190	5.99
200	6.17
210	6.32
310	7.50

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 327. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SELENIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	501	Chistov, S.F., Chernov, A.P., and Dombovskii, S.A.	1968	L	133-414	As_2Se_3	Arsenic selenide; polycrystalline specimen; obtained by heating glass at 573 K for 3 days; specimen cooled to temperature of liquid nitrogen; heating rate 1.6 degree per min; author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.
2*	501	Chistov, S.F., et al.	1968	L	130-414	As_2Se_3	Arsenic selenide; vitreous specimen; cooled to temperature of liquid nitrogen and heated at a rate of 1.6 degree per min; author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.
3*	870	Lashkarev, G.V., Dudnik, E.M., and Paderno, Yu.B.	1966	L	300, 800	EuSe	Europium selenide; starting materials 99.5+ pure Eu and 99.992 pure SeO_2; prepared by heating powders.
4*	523	Novikova, S.I.	1969	L	27-343	Ga_2Se_3	Gallium selenide; polycrystalline specimen prepared from 99.999 pure elements; data compiled from six series of measurements.
5*	870	Lashkarev, G.V., Dudnik, E.M., and Paderno, Yu.B.	1966	L	300, 800	La_2Se_3	Lanthanum selenide; starting materials 99.95+ pure La and 99.992 pure SeO_2; prismatic specimen prepared by heating powders.
6*	871	Zhdanova, V.V., Lukina, V.I., and Hovikova, S.I.	1966	L	25-498	HgSe	Mercury selenide; diamond-type lattice, undoped crystal sample, measured from liquid nitrogen temperature to 500 K.
7*	871	Zhdanova, V.V., et al.	1966	L	85-502	HgSe	Mercury selenide; similar to the above specimen; doped sample.
8*	872	Singh, H.P. and Dayal, B.	1969	X	307-650	HgSe	Mercury selenide; dimension, 0.3 mm diameter specimen; pure sample annealed at 423 K for 3 hr; placed in 0.3 mm ID quartz capillary; lattice parameter reported at 307 K as 6.0864 Å; 6.0863 Å at 293 K determined by graphical extrapolation; coefficient of thermal linear expansion also reported.
9*	870	Lashkarev, G.V., Dudnik, E.M., and Paderno, Yu.B.	1966	L	300, 800	Nd_2Se_3	Neodymium selenide; starting materials 99.95+ pure Nd and 99.992 pure SeO_2; prepared by heating powders together.
10*	870	Lashkarev, G.V., Dudnik, E.M., and Paderno, Yu.B.	1966	L	300, 800	Pr_2Se_3	Praeseodymium selenide; starting materials 99.95+ pure Pr and 99.992 pure SeO_2; prismatic specimen prepared by heating powders.
11*	870	Lashkarev, G.V., Dudnik, E.M., and Paderno, Yu.B.	1966	L	300, 800	Sm_2Se_3	Samarium selenide; starting materials 99.5+ pure Sm, 99.992 SeO_2; prismatic specimen prepared by heating powders.
12*	873	Evans, B.L. and Hazelwood, R.A.	1969	X	82-361	$SnSe_2$	Tin selenide; compound prepared from 5 N purity Sn, 8 N purity Se, contain in evacuated silica tube with stoichiometric amount of elements, heating to 573 K for 24 hr; crystal thickness ranged from 2 to 100 μm with surface areas up to 2 cm^2; iodine present < 0.01.
13*	843	Lander, G.H. and Mueller, M.H.	1971	X	200-300	USe	Uranium selenide; particle size ~ 40 μm; crystal structure of NaCl, powder was depressed at 527 kg/cm^2 into flat disk, placed in milled recess in copper holder; disk covered with 0.0005 cm Mylar window, sealed with copper frame and resin; lattice parameter reported at 300 K as 5.75 Å.

* No figure given.

DATA TABLE 327. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SELENIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*,‡	
133	-0.027
145	-0.025
158	-0.023
171	-0.021
184	-0.019
197	-0.016
210	-0.014
220	-0.012
232	-0.010
243	-0.009
254	-0.007
265	-0.005
278	-0.003
288	-0.001
293	0.000
300	0.001
312	0.003
326	0.006
336	0.007
346	0.009
357	0.011
369	0.014
382	0.016
395	0.019
405	0.021
414	0.022
CURVE 2*,‡	
130	-0.034
134	-0.033
140	-0.032
145	-0.031
151	-0.030
158	-0.028
164	-0.027
170	-0.026
179	-0.024
184	-0.023
191	-0.022
198	-0.020
204	-0.019
211	-0.017
217	-0.016
CURVE 2 (cont.)*,‡	
231	-0.013
236	-0.012
242	-0.011
249	-0.009
257	-0.008
263	-0.006
270	-0.005
281	-0.003
289	-0.001
293	0.000
295	0.000
303	0.002
310	0.004
317	0.005
323	0.007
331	0.008
338	0.010
344	0.011
351	0.013
358	0.014
365	0.016
371	0.017
380	0.020
387	0.021
395	0.023
401	0.025
408	0.027
414	0.028
CURVE 3*	
300	0.013
800	0.943
CURVE 4*,‡	
27	-0.180
29	-0.179
36	-0.178
39	-0.178
42	-0.177
48	-0.175
52	-0.174
58	-0.172
CURVE 4 (cont.)*,‡	
62	-0.171
73	-0.166
76	-0.164
82	-0.161
84	-0.160
90	-0.157
93	-0.156
99	-0.152
105	-0.149
110	-0.146
120	-0.139
129	-0.134
138	-0.127
147	-0.121
156	-0.114
158	-0.113
177	-0.098
195	-0.083
201	-0.079
211	-0.070
221	-0.062
229	-0.055
239	-0.047
258	-0.031
265	-0.025
277	-0.014
285	-0.007
296	0.002
304	0.010
321	0.025
343	0.045
CURVE 5*	
300	0.008
800	0.603
CURVE 6*,‡	
25	0.027
33	0.022
40	0.017
51	0.010
60	0.005
CURVE 6 (cont.)*,‡	
69	0.001
78	-0.002
80	-0.003
81	-0.003
86	-0.005
92	-0.0065
95	-0.007
99	-0.007
108	-0.009
112	-0.010
116	-0.010
122	-0.011
144	-0.012
148	-0.013
154	-0.013
161	-0.013
165	-0.013
174	-0.013
192	-0.012
202	-0.011
213	-0.010
221	-0.009
228	-0.008
238	-0.007
245	-0.006
256	-0.005
257	-0.005
260	-0.005
272	-0.003
276	-0.002
281	-0.002
283	-0.001
287	-0.001
293	0.000
298	0.001
301	0.001
320	0.004
341	0.007
361	0.010
379	0.013
391	0.015
402	0.017
416	0.020
430	0.022
CURVE 6 (cont.)*,‡	
441	0.024
456	0.027
468	0.029
480	0.031
494	0.033
498	0.034
CURVE 7*,‡	
85	-0.001
91	-0.003
106	-0.006
124	-0.009
137	-0.010
140	-0.010
151	-0.011
160	-0.011
173	-0.012
177	-0.012
183	-0.012
198	-0.011
209	-0.010
224	-0.009
259	-0.005
267	-0.004
293	-0.000
314	0.003
351	0.009
371	0.012
412	0.019
446	0.025
449	0.026
476	0.030
502	0.035
CURVE 8*,‡	
307	0.007
423	0.063
488	0.096
538	0.122
603	0.157
650	0.183
CURVE 9*	
300	0.009
800	0.684
CURVE 10*	
300	0.009
800	0.659
CURVE 11*	
300	0.010
800	0.750
CURVE 12*	
82	-0.520
143	-0.357
188	-0.289
231	-0.273
268	-0.079
293	0.000
301	0.066
361	0.168
CURVE 13*	
200	-0.132
293	0.000
300	0.010

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 327. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS SELENIDES

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

CURVE 1*, ‡

T	α
133	1.68
145	1.71
158	1.71
171	1.68
184	1.68
197	1.68
210	1.77
220	1.65
232	1.71
243	1.71
254	1.71
265	1.71
278	1.69
288	1.69
293	1.69
300	1.69
312	1.69
326	1.77
336	1.77
346	1.85
357	1.92
369	1.85
382	2.03
395	1.99
405	2.00
414	1.96

CURVE 2*, ‡

T	α
130	1.95
134	1.93
140	1.93
145	2.16
151	2.02
158	1.97
164	1.97
170	1.99
179	2.05
184	1.98
191	2.10
198	2.24
204	2.07
211	2.18
217	2.07
231	2.07

CURVE 2 (cont.)*, ‡

T	α
236	2.22
242	2.22
249	2.08
257	2.08
263	2.16
270	2.06
281	2.14
289	2.13
293	2.15
295	2.19
303	2.13
310	2.25
317	2.27
323	2.13
331	2.18
338	2.20
344	2.20
351	2.31
358	2.37
365	2.43
371	2.33
380	2.57
387	2.55
395	2.45
401	2.63
408	2.69
414	2.61

CURVE 4*, ‡

T	α
27	1.51
29	1.83
36	1.78
39	2.21
42	2.70
48	2.68
52	3.14
58	3.33
62	4.13
73	4.50
76	4.94
82	5.11
84	5.44
90	5.28
93	5.52

CURVE 4 (cont.)*, ‡

T	α
99	5.60
105	5.65
110	6.23
120	6.62
129	6.62
138	7.02
147	7.35
156	7.77
158	7.44
177	7.93
195	8.24
201	8.10
211	8.20
221	8.39
229	8.25
239	8.69
258	8.58
265	8.48
277	8.72
285	8.81
296	8.87
304	8.96
321	9.09
343	9.22

CURVE 6*, ‡

T	α
25	-7.00
33	-7.12
40	-6.62
51	-5.80
60	-5.05
69	-4.03
78	-3.30
80	-3.07
81	-2.91
86	-2.58
92	-2.23
95	-2.11
99	-1.88
108	-1.52
112	-1.44
116	-1.29
120	-1.00
144	-0.48

CURVE 6 (cont.)*, ‡

T	α
148	-0.37
154	-0.20
161	-0.01
165	0.00
174	0.37
192	0.76
202	0.84
213	0.98
221	1.06
228	1.09
238	1.18
245	1.21
256	1.27
257	1.14
260	1.29
272	1.36
276	1.31
281	1.36
283	1.47
287	1.42
293	1.46
298	1.51
301	1.40
320	1.54
341	1.61
361	1.61
379	1.64
391	1.68
402	1.70
416	1.70
430	1.65
441	1.79
456	1.79
468	1.84
480	1.76
494	1.76
498	1.89

CURVE 7*, ‡

T	α
85	-2.95
91	-2.44
106	-1.76
124	-1.22
137	-0.90

CURVE 7 (cont.)*, ‡

T	α
140	-0.56
151	-0.56
160	-0.29
173	-0.03
177	-0.10
183	0.30
198	0.56
209	0.78
224	1.07
259	1.23
267	1.36
293	1.46
314	1.52
351	1.59
371	1.65
412	1.77
446	1.69
449	1.79
476	1.74
502	1.81

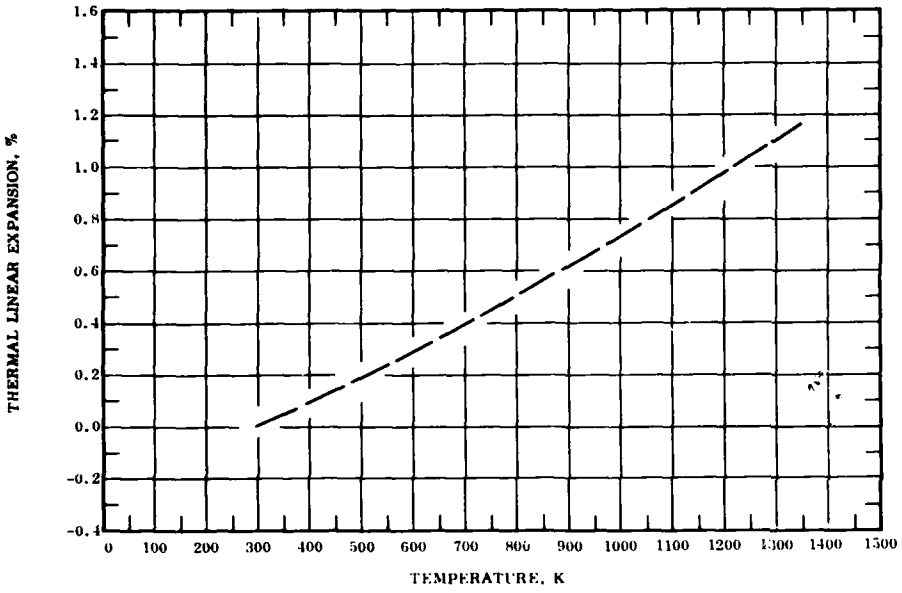
CURVE 8*, ‡

T	α
307	4.76
423	4.99
488	5.13
538	5.26
603	5.44
650	5.57

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 328R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF TRICHROMIUM SILICIDE Cr_3Si



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	9.2
300	0.006	9.3
400	0.100	9.5
500	0.197	9.8
600	0.296	10.1
700	0.399	10.4
800	0.505	10.8
900	0.615	11.2
1000	0.730	11.7
1100	0.849	12.2
1200	0.973	12.7
1300	1.102	13.2
1350	1.169	13.5

REMARKS

The provisional values are based on the data for pure sample (curve 2) and are considered accurate to within ±7% at temperatures below 1100 K and ±10% above 1100 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.262 + 8.713 \times 10^{-4}\ T + 6.574 \times 10^{-5}\ T^2 + 5.510 \times 10^{-11}\ T^3$$

The tabulated values for the coefficient of thermal expansion are derived primarily by differentiating the above equation and are considered accurate to about ±10%.

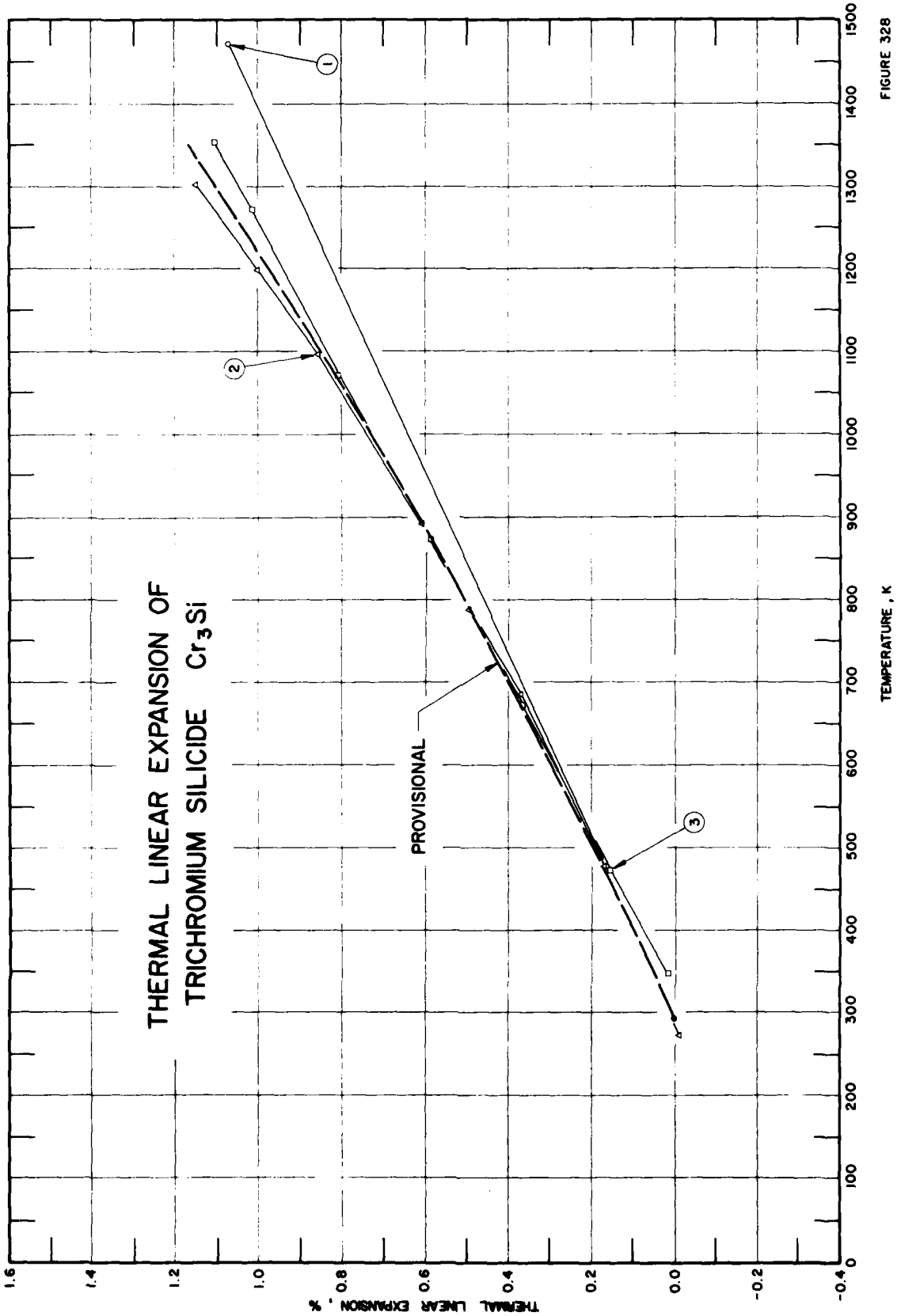

THERMAL LINEAR EXPANSION OF
TRICHROMIUM SILICIDE Cr_3Si
PROVISIONAL
1
2
3
THERMAL LINEAR EXPANSION , %
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
TEMPERATURE , K
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 328

SPECIFICATION TABLE 328. THERMAL LINEAR EXPANSION OF TRICHROMIUM SILICIDE Cr_3Si

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	437	Frantsevich, I.N., Zhurakovskii, E.A., and Lyashchenko, A.B.	1967	X	293,1473		84.0 Cr, 15.1 Si, and 15.22 theoretical content of metalloid; sample prepared from powder by the vacuum sintering of pressed block.
2	10	Mauer, F.A. and Bolz, L.H.	1955	X	273-1303		99.8' pure, < 0.1 V, < 0.01 any other impurity; powder expansion measured in helium atmosphere; zero-point correction is -0.013% at 293 K.
3	884	Neshpor, V.S. and Reznichenko, M.I.	1963		293-1353		85.0 Cr, 14.9 total Si; sintered, hot pressed, and annealed; fusion temperature 1983 K.

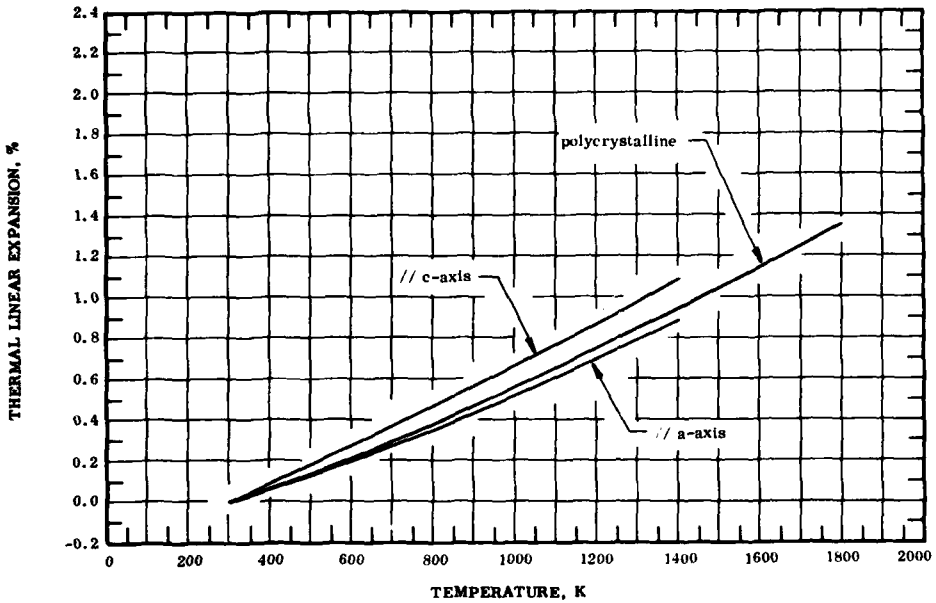
DATA TABLE 328. THERMAL LINEAR EXPANSION OF TRICHROMIUM SILICIDE Cr_3Si

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
1473	1.073
CURVE 2	
273	-0.013
299	0.004
479	0.167
685	0.369
788	0.496
891	0.604
1097	0.858
1200	1.000
1303	1.150

T	$\Delta L/L_0$
CURVE 3	
293	0.000
348	0.019
473	0.155
673	0.365
873	0.582
1073	0.802
1273	1.018
1353	1.105

FIGURE AND TABLE NO. 329R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF MOLYBDENUM DISILICIDE $MoSi_2$



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	6.8
300	0.004	0.006	0.005	6.8
400	0.068	0.090	0.075	7.3
500	0.137	0.178	0.151	7.7
600	0.209	0.269	0.229	8.1
700	0.285	0.364	0.311	8.4
800	0.365	0.462	0.397	8.7
900	0.447	0.562	0.485	8.9
1000	0.531	0.664	0.575	9.1
1100	0.617	0.768	0.667	9.3
1200	0.704	0.873	0.760	9.4
1300	0.793	0.979	0.855	9.6
1400	0.882	1.086	0.950	9.7
1500			1.045	9.8
1600			1.139	9.9
1700			1.233	9.9
1800			1.326	10.0

REMARKS

The recommended values for the polycrystalline sample are calculated from the selected axial thermal expansion values (curves 9 and 10) and agree with most of the experimental data. The recommended values are considered accurate to within ± 5% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.157 + 4.500 \times 10^{-4} T + 3.108 \times 10^{-7} T^2 - 7.319 \times 10^{-11} T^3$

// c-axis: $\Delta L/L_0 = -0.218 + 6.675 \times 10^{-4} T + 2.800 \times 10^{-7} T^2 - 6.551 \times 10^{-11} T^3$

polycrystalline: $\Delta L/L_0 = -0.177 + 5.225 \times 10^{-4} T + 2.998 \times 10^{-7} T^2 - 7.005 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are primarily derived by differentiating the above equation for polycrystalline sample and are considered accurate to about ± 10%.

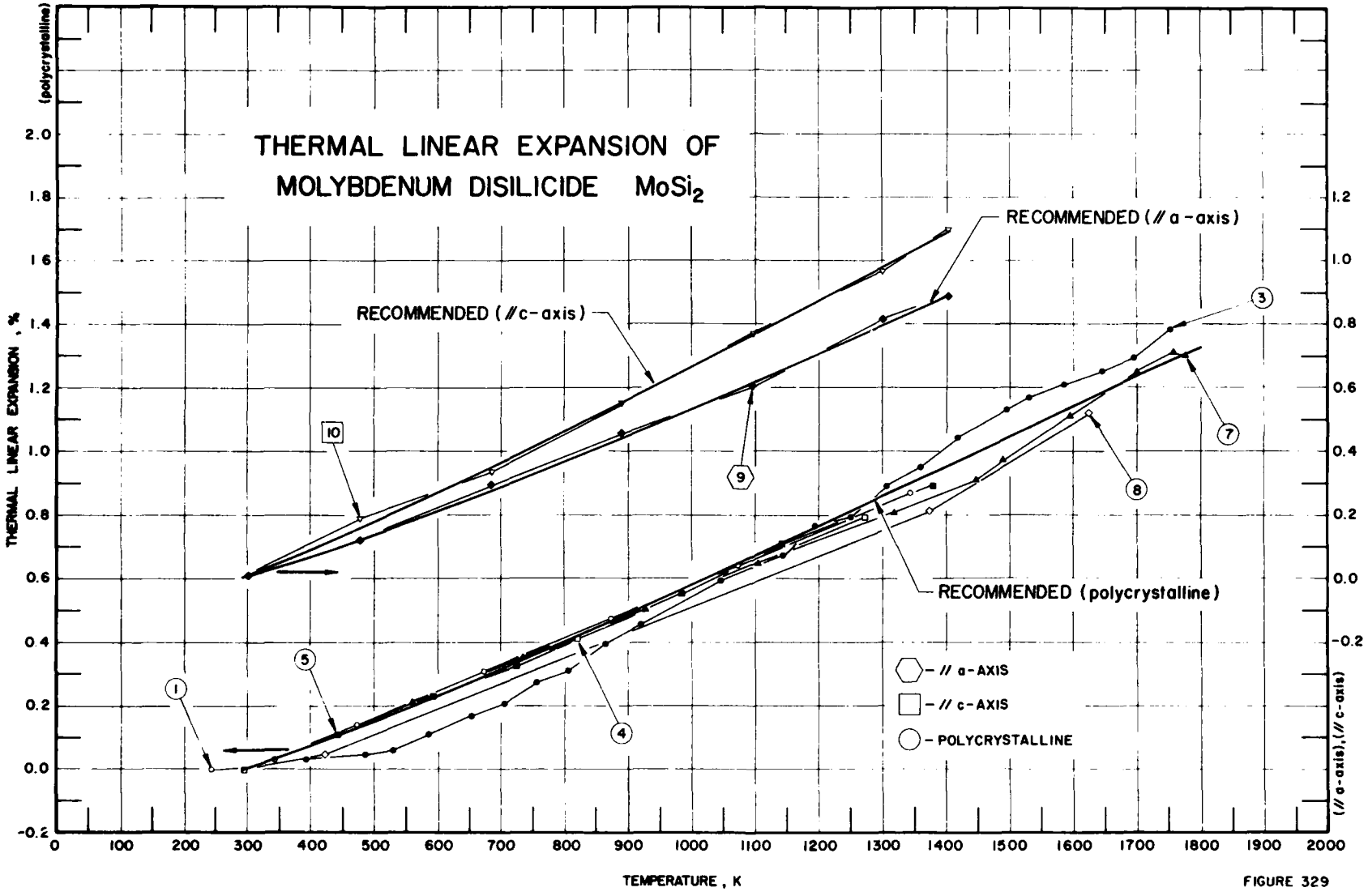

THERMAL LINEAR EXPANSION OF
MOLYBDENUM DISILICIDE $MoSi_2$
RECOMMENDED (// a-axis)
RECOMMENDED (// c-axis)
RECOMMENDED (polycrystalline)
10
9
3
7
8
5
1
4
- // a-AXIS
- // c-AXIS
- POLYCRYSTALLINE
THERMAL LINEAR EXPANSION, % (polycrystalline)
(// a-axis), (// c-axis)
TEMPERATURE, K
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
-0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0
-0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2

FIGURE 329

SPECIFICATION TABLE 329. THERMAL LINEAR EXPANSION OF MOLYBDENUM DISILICIDE $MoSi_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	884	Neshpor, V.S. and Reznichenko, M.I.	1963	L	293-1343		63.2 Mo, 37.0 total Si (0.2 free); sintered, hot pressed, and annealed; fusion temperature 2303 K.
2*	454	Nowak, J.M.	1961	L	293-1274		Dimension 1.27 cm diameter x 7.62 cm long; specimen stamped at about 1652.6 K; zero-point correction -0.005% at 293 K.
3	895	Fieldhouse, I.B. and Lang, J.I.	1961	L	299-1753		61.5-63.5 Mo, 35-37 Si; slip cast; density 5.80 g cm^{-3}.
4	374	Anthony, F.M. and Pearl, H.A.	1960	L	299-1274	E-34	Specimen prepared by ball-milled 62-63.5 Mo, 36-37 Si for several hours, dried, slip cast, dried again and sintered.
5	896	Booker, J., Paine, R.M., and Stonehouse, A.J.	1960	T	444-1490		Bar specimen 1.27 cm x 1.27 cm x 8.22 cm long; heating run in argon.
6	896	Booker, J., et al.	1960	T	1400,1219		The above specimen, cooling run.
7	896	Booker, J., et al.	1960	T	560-1779		Similar to the above specimen; heating run.
8	896	Booker, J., et al.	1960	T	1626-422		The above specimen; cooling run.
9	10	Mauer, F.A. and Bolz, L.H.	1955	X	273-1406		99.7+ pure, < 0.1 Al, Fe; < 0.01 any other impurity; 36.2 Si (36.9 Si theoretically); commercial powder sintered at 1373 K; expansion on a-axis measured in helium atmosphere; zero-point correction -0.013% at 293 K.
10	10	Mauer, F.A. and Bolz, L.H.	1955	X	273-1406		The above specimen; expansion on c-axis; zero-point correction -0.015% at 293 K.
11*	889	Verkhorobin, L.F. and Matyushenko, N.N.	1963	X	293,993		Commercial-purity Mo, 10 x 10 mm plate annealed in vacuum in 99.9 pure Si powder at 1473-1573 K, 100 μ thick MoSi layer formed, expansion measured from 226 reflection; reported error ± 7%; expansion reported along a-axis.

* Not shown in figure.

DATA TABLE 329. THERMAL LINEAR EXPANSION OF MOLYBDENUM DISILICIDE $MoSi_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

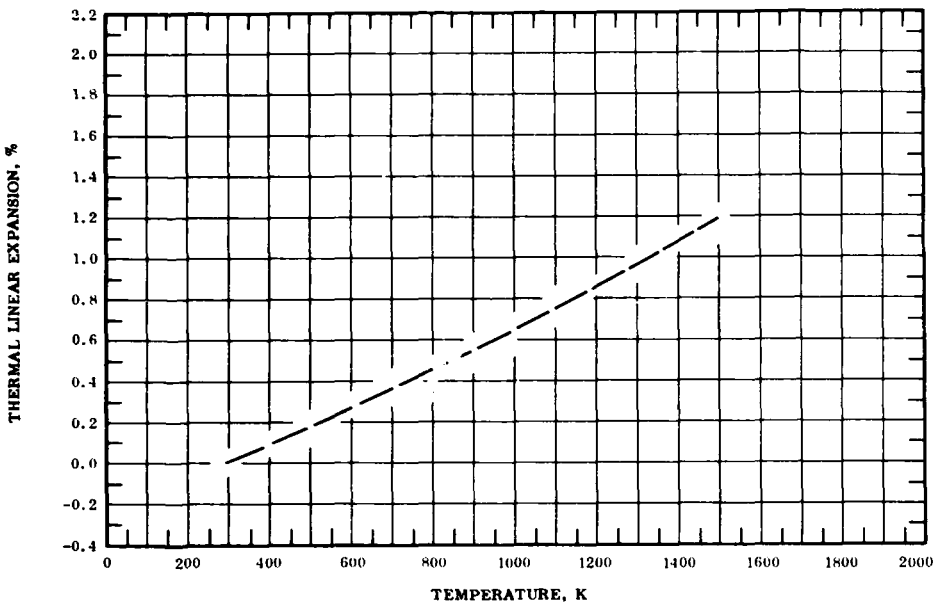
T	$\Delta L/L_0$
CURVE 1	
293	0.000
343	0.035
473	0.140
673	0.305
873	0.475
1073	0.640
1273	0.815*
1343	0.864
CURVE 2*	
293	0.000
822	0.417
1274	0.795
CURVE 3	
299	0.001*
353	0.010*
394	0.030
487	0.042
530	0.061
585	0.113
653	0.169
706	0.201
756	0.275
807	0.301
864	0.398
920	0.455
1046	0.595
1088	0.623
1142	0.675
1197	0.763
1251	0.792
1309	0.888
1361	0.951
1420	1.041
1495	1.131
1532	1.171
1587	1.201
1649	1.251
1695	1.291
1753	1.381

T	$\Delta L/L_0$
CURVE 4	
299	0.000
822	0.414
1274	0.794
CURVE 5	
444	0.113
595	0.226
726	0.329
825	0.428*
984	0.557
1144	0.703
1270	0.802
1380	0.887
1490	0.973
CURVE 6	
1400	0.843
1219	0.627
CURVE 7	
560	0.215
735	0.356
927	0.510
1105	0.651
1319	0.802
1449	0.910
1596	1.113
1701	1.253
1759	1.319
1779	1.300
CURVE 8	
1626	1.121
1376	0.817
422	0.048
CURVE 9	
273	-0.013
303	0.006

T	$\Delta L/L_0$
CURVE 9 (cont.)	
479	0.121
685	0.296
891	0.458
1097	0.608
1303	0.818
1406	0.889
CURVE 10	
273	-0.015*
303	0.008*
479	0.189
685	0.337
891	0.555
1097	0.769
1303	0.967
1406	1.100
CURVE 11*	
293	0.000
993	0.641

* Not shown in figure.

FIGURE AND TABLE NO. 330R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF TANTALUM DISILICIDE $TaSi_2$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	8.7
300	0.006	8.7
400	0.093	8.7
500	0.180	8.8
600	9.267	8.8
700	0.356	9.0
800	0.447	9.2
900	0.541	9.5
1000	0.638	9.9
1100	9.738	10.3
1200	0.843	10.7
1300	0.953	11.3
1400	1.069	11.9
1500	1.191	12.5

REMARKS

The provisional values are considered accurate to within ± 15% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.259 + 9.095 \times 10^{-4}\, T - 1.145 \times 10^{-7}\, T^2 + 1.019 \times 10^{-10}\, T^3$$

The tabulated values for the coefficient of thermal expansion are primarily calculated by differentiating the above equation and are considered accurate to about ± 15%.

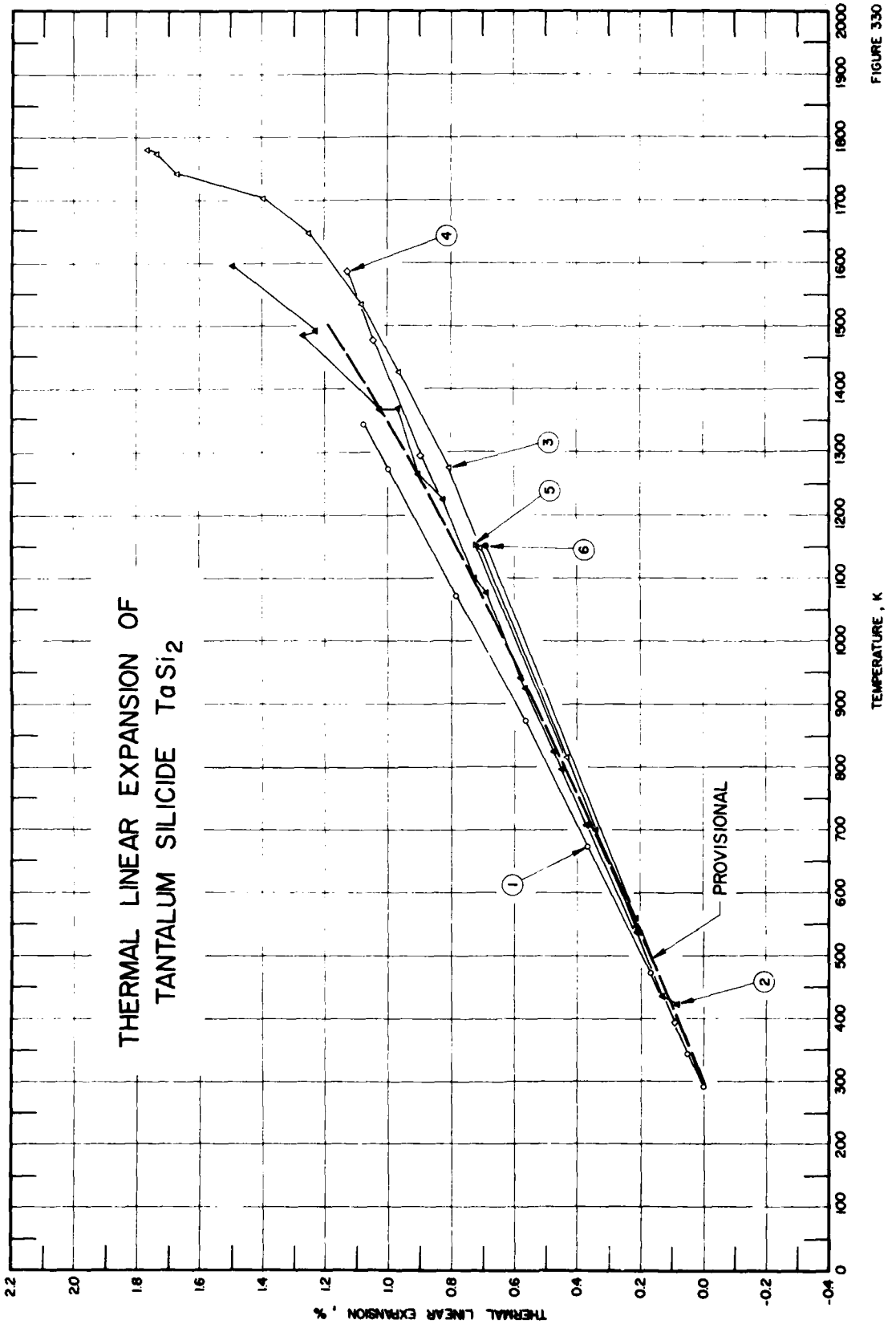

THERMAL LINEAR EXPANSION OF
TANTALUM SILICIDE $TaSi_2$
PROVISIONAL
1
2
3
4
5
6
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-.04
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 330

SPECIFICATION TABLE 330. THERMAL LINEAR EXPANSION OF TANTALUM SILICIDE $TaSi_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	884	Neshpor, V.S. and Reznichenko, M.I.	1963		293-1343		77.4 Ta, 23.9 total Si (0.6 free); sintered, hot pressed, and annealed.
2	896	Booker, J., Paine, R.M., and Stonehouse, A.J.	1960	T	422-1598		Bar specimen 0.63 cm x 1.27 cm x 8.22 cm long; expansion measured in argon; zero-point correction -0.3% at 293 K.
3	896	Booker, J., et al.	1960	T	548-1780		Similar to the above specimen; sample was preoxidized; heating run.
4	896	Booker, J., et al.	1960	T	1589-394		The above specimen; cooling run.
5	889	Verkhorobin, L.F. and Matyushenko, N.N.	1963	X	293,1153		Commercial-purity Nb, 10 x 10 mm plate, annealed in vacuum in 99.9 pure Si powder at 1473-1573 K, 100 μ thick of $TaSi_2$ layer formed; expansion measured from 414 reflection; reported error ± 6%.
6	889	Verkhorobin, L.F. and Matyushenko, N.N.	1963	X	293,1153		The above specimen; expansion measured from 420 reflection.

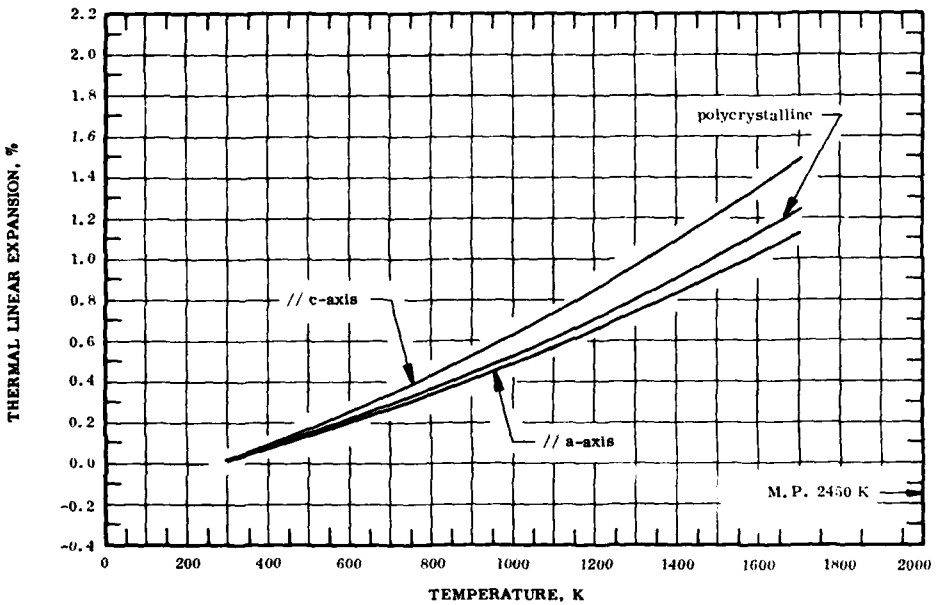
DATA TABLE 330. THERMAL LINEAR EXPANSION OF TANTALUM SILICIDE $TaSi_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
343	0.050
473	0.170
673	0.366
873	0.567
1073	0.785
1273	1.000
1343	1.080
CURVE 2	
422	0.087
437	0.132
538	0.215
560	0.215
700	0.344
708	0.371
798	0.449
825	0.476
925	0.566
941	0.580
1078	0.689
1100	0.726
1224	0.829
1266	0.902
1369	0.971
1369	1.028
1485	1.271
1493	1.227
1598	1.497
CURVE 3	
548	0.212
818	0.432
1150	0.705
1276	0.805
1426	0.966
1536	1.082
1649	1.254
1702	1.399
1741	1.671
1773	1.736
1780	1.767
CURVE 4	
1589	1.128
1479	1.044
1295	0.898
394	0.091
CURVE 5	
293	0.000*
1153	0.720
CURVE 6	
293	0.000*
1153	0.690

* Not shown in figure.

FIGURE AND TABLE NO. 331R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF TUNGSTEN DISILICIDE WSi_2



RECOMMENDED VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

	// a-axis	// c-axis	polycrystalline	
T	$\Delta L/L_0$	$\Delta L/L_0$	$\Delta L/L_0$	α
293	0.000	0.000	0.000	7.2
300	0.005	0.006	0.005	7.2
400	0.073	0.086	0.077	7.2
500	0.141	0.168	0.150	7.3
600	0.208	0.253	0.223	7.4
700	0.277	0.341	0.298	7.6
800	0.346	0.432	0.375	7.8
900	0.418	0.527	0.454	8.1
1000	0.491	0.626	0.536	8.4
1100	0.568	0.731	0.622	8.8
1200	0.648	0.842	0.712	9.2
1300	0.732	0.958	0.807	9.7
1400	0.820	1.082	0.908	10.3
1500	0.914	1.213	1.014	10.9
1600	1.014	1.352	1.126	11.6
1700	1.120	1.499	1.246	12.3

REMARKS

The recommended values for the polycrystalline sample are calculated from the selected axial thermal expansion values. This result is recommended in preference to the reported experimental data for hot-pressed samples on the suspicion that these samples exhibit partial preferential orientation. The recommended values are considered accurate to within ± 5% and are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.209 + 7.467 \times 10^{-4} T - 1.425 \times 10^{-7} T^2 + 9.596 \times 10^{-11} T^3$

// c-axis: $\Delta L/L_0 = -0.231 + 7.874 \times 10^{-4} T - 2.340 \times 10^{-8} T^2 + 9.343 \times 10^{-11} T^3$

polycrystalline: $\Delta L/L_0 = -0.216 + 7.598 \times 10^{-4} T - 1.018 \times 10^{-7} T^2 + 9.464 \times 10^{-11} T^3$

The tabulated values for the coefficient of thermal expansion are primarily calculated by differentiating the above equation for polycrystalline sample and are considered accurate to about ± 7%.

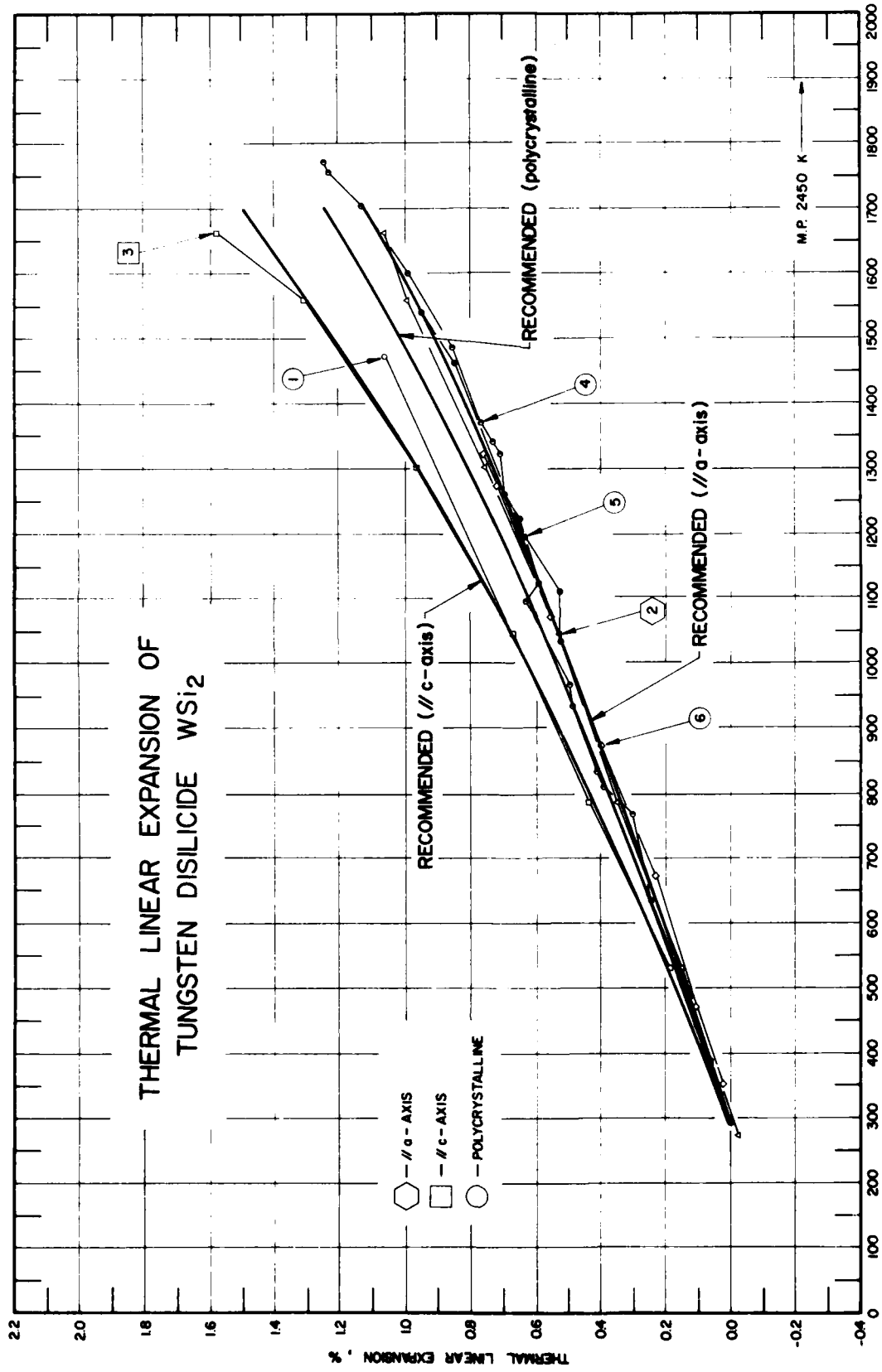

THERMAL LINEAR EXPANSION OF
TUNGSTEN DISILICIDE WSi_2
RECOMMENDED (polycrystalline)
RECOMMENDED (// c-axis)
RECOMMENDED (// a-axis)
M.P. 2450 K
— // a-AXIS
— // c-AXIS
— POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K

FIGURE 331

SPECIFICATION TABLE 331. THERMAL LINEAR EXPANSION OF TUNGSTEN DISILICIDE WSi_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	437	Frantsevich, I.N., Zhurakovskii, E.A., and Lyashchenko, A.B.	1967	X	293, 1473		75.6 W, 23.7 Si, and 23.4 theoretical constant of metalloid; sample prepared from powder by the vacuum sintering at pressed block.
2	10	Mauer, F.A. and Bolz, L.H.	1957	X	273-1663		Prepared by R.F. Walker of NBS from 99.7* Si and "high purity" W obtained from Fairmount and Chemical Co., Inc.; heated together 1 hr at 1573 K; tetragonal structure; expansion along a-axis measured in helium atmosphere; zero-point correction is -0.022% at 293 K.
3	10	Mauer, F.A. and Bolz, L.H.	1957	X	273-1663		The above specimen; expansion measured along c-axis; zero-point correction is -0.023% at 293 K.
4	897	Booker, J., Paine, R.M., and Stonehouse, A.J.	1960	T	299-1772	Pressing No. H.P. 347	Grain size ~ 27 μm, dimension rectangular 1.27 cm x 0.62 cm x 8.22 cm long, hot pressed with Mo, pre-oxidized for 1 hr at 1700 K before measurement, measurement taken in air (> 1366 K) and in argon (< 1366 K), 100% absolute density.
5	897	Booker, J., et al.	1960	T	1541-299	Pressing No. H.P. 347	The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.004% at 293 K.
6	884	Neshpor, V.S. and Reznichenko, M.I.	1963		293-1323		76.0 W, 23.8 total Si (0.2 free); sintered, hot pressed, and annealed; fusion temperature 2438 K.

DATA TABLE 331. THERMAL LINEAR EXPANSION OF TUNGSTEN DISILICIDE WSi_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
293	0.000
1473	1.062

CURVE 2

T	$\Delta L/L_0$
273	-0.022
293	0.000*
531	0.155
788	0.348
1046	0.527
1303	0.759
1561	0.993
1663	1.060

CURVE 3

T	$\Delta L/L_0$
273	-0.023*
293	0.000*
531	0.185
788	0.438
1046	0.664
1303	0.964
1561	1.310
1663	1.580

CURVE 4

T	$\Delta L/L_0$
299	0.004
387	0.063
442	0.103
560	0.184
634	0.242
768	0.304
810	0.393
835	0.412
936	0.481
968	0.494
1039	0.522
1099	0.634
1124	0.592
1223	0.645
1260	0.698
1322	0.701
1341	0.734
1373	0.768
1488	0.858

CURVE 4 (cont.)

T	$\Delta L/L_0$
1602	0.984
1705	1.134
1758	1.238
1772	1.244

CURVE 5

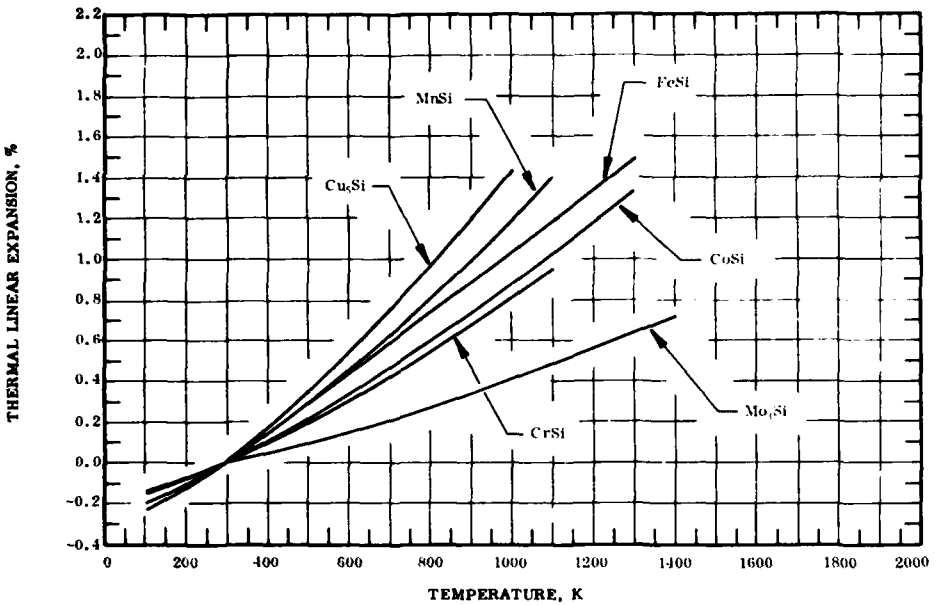
T	$\Delta L/L_0$
1541	0.944
1465	0.849
1197	0.636
1113	0.524
299	0.004

CURVE 6

T	$\Delta L/L_0$
293	0.000*
351	0.028
473	0.101
673	0.235
873	0.397
1073	0.550
1273	0.720
1323	0.760

* Not shown in figure.

FIGURE AND TABLE NO. 332R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICIDES



REMARKS

The recommended values are based on the most recent measurements for pure samples. These values are considered accurate to within ± 5% and are represented by the following equations:

CrSi: $\Delta L/L_0 = -0.193 + 4.429 \times 10^{-4}\ T + 8.052 \times 10^{-7}\ T^2 - 2.392 \times 10^{-10}\ T^3$

CoSi: $\Delta L/L_0 = -0.219 + 5.477 \times 10^{-4}\ T + 7.526 \times 10^{-7}\ T^2 - 1.990 \times 10^{-10}\ T^3$ (293–1300 K)

Cu_5Si: $\Delta L/L_0 = -0.314 + 6.404 \times 10^{-4}\ T + 1.617 \times 10^{-6}\ T^2 - 5.087 \times 10^{-10}\ T^3$

FeSi: $\Delta L/L_0 = -0.438 + 1.502 \times 10^{-3}\ T - 3.808 \times 10^{-8}\ T^2 + 1.649 \times 10^{-11}\ T^3$ (293–1300 K)

MnSi: $\Delta L/L_0 = -0.301 + 7.602 \times 10^{-4}\ T + 9.868 \times 10^{-7}\ T^2 - 2.502 \times 10^{-10}\ T^3$ (293–1100 K)

Mo_5Si: $\Delta L/L_0 = -0.073 + 1.075 \times 10^{-4}\ T + 5.156 \times 10^{-7}\ T^2 - 1.354 \times 10^{-10}\ T^3$

The tabulated values for the coefficient of thermal expansion are derived primarily by differentiating the above equations and giving some weight to experimental data wherever available. These values are considered accurate to about ± 10%.

RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, $10^{-6}\ K^{-1}$]

	CrSi		CoSi		Cu_5Si	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α	$\Delta L/L_0$	α
100	-0.140	4.9	-0.154	5.5		
150	-0.109	6.4	-0.122	7.2		
200	-0.075	7.4	-0.083	8.4		
250	-0.036	8.0	-0.039	9.0		
293	0.000	8.5	0.000	9.3	0.000	14.6
300	0.005	8.6	0.009	9.4	0.010	14.7
400	0.097	9.7	0.108	10.5	0.169	16.9
500	0.199	10.7	0.218	11.5	0.347	18.8
600	0.311	11.5	0.338	12.3	0.543	20.3
700	0.429	12.2	0.465	13.1	0.753	21.6
800	0.554	12.7	0.599	13.7	0.973	22.5
900	0.683	13.1	0.739	14.2	1.202	23.2
1000	0.815	13.4	0.882	14.6	1.436	23.5
1100	0.950	13.5	1.029	14.8		
1200			1.178	14.9		
1300			1.328	15.0		

	FeSi		MnSi		Mo_5Si	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α	$\Delta L/L_0$	α
100	-0.230	5.50	-0.196	6.3		
150	-0.190	10.74	-0.158	8.9		
200	-0.130	13.10	-0.109	10.8		
250	-0.062	14.20	-0.050	11.9		
293	0.000	14.70	0.000	12.5	0.000	3.9
300	0.009	14.70	0.009	12.6	0.002	3.9
400	0.158	14.73	0.145	14.1	0.044	4.6
500	0.305	14.75	0.295	15.5	0.093	5.3
600	0.453	14.78	0.457	16.7	0.148	5.8
700	0.600	14.80	0.629	17.8	0.209	6.3
800	0.747	14.81	0.811	18.6	0.274	6.7
900	0.895	14.82	1.000	19.3	0.343	7.0
1000	1.042	14.82	1.196	19.8	0.415	7.3
1100	1.190	14.83	1.397	20.2	0.489	7.5
1200	1.338	14.83			0.565	7.6
1300	1.486	14.83			0.641	7.7
1400					0.717	7.7

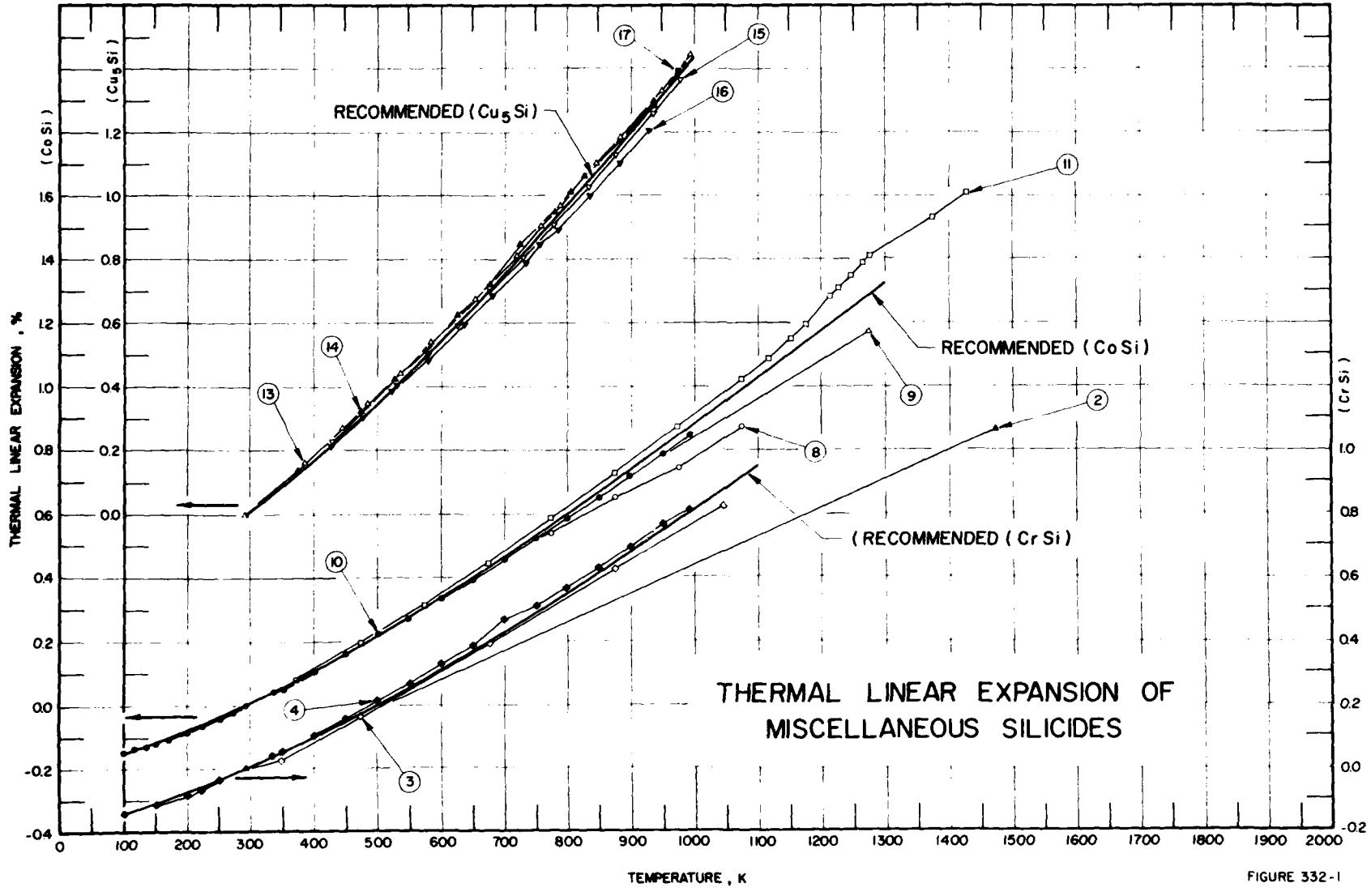

THERMAL LINEAR EXPANSION , %
(Cu5Si)
(CoSi)
(CrSi)
RECOMMENDED (Cu5Si)
RECOMMENDED (CoSi)
(RECOMMENDED (CrSi)
THERMAL LINEAR EXPANSION OF
MISCELLANEOUS SILICIDES
TEMPERATURE , K
17
15
16
11
14
13
9
2
8
10
4
3

FIGURE 332-1

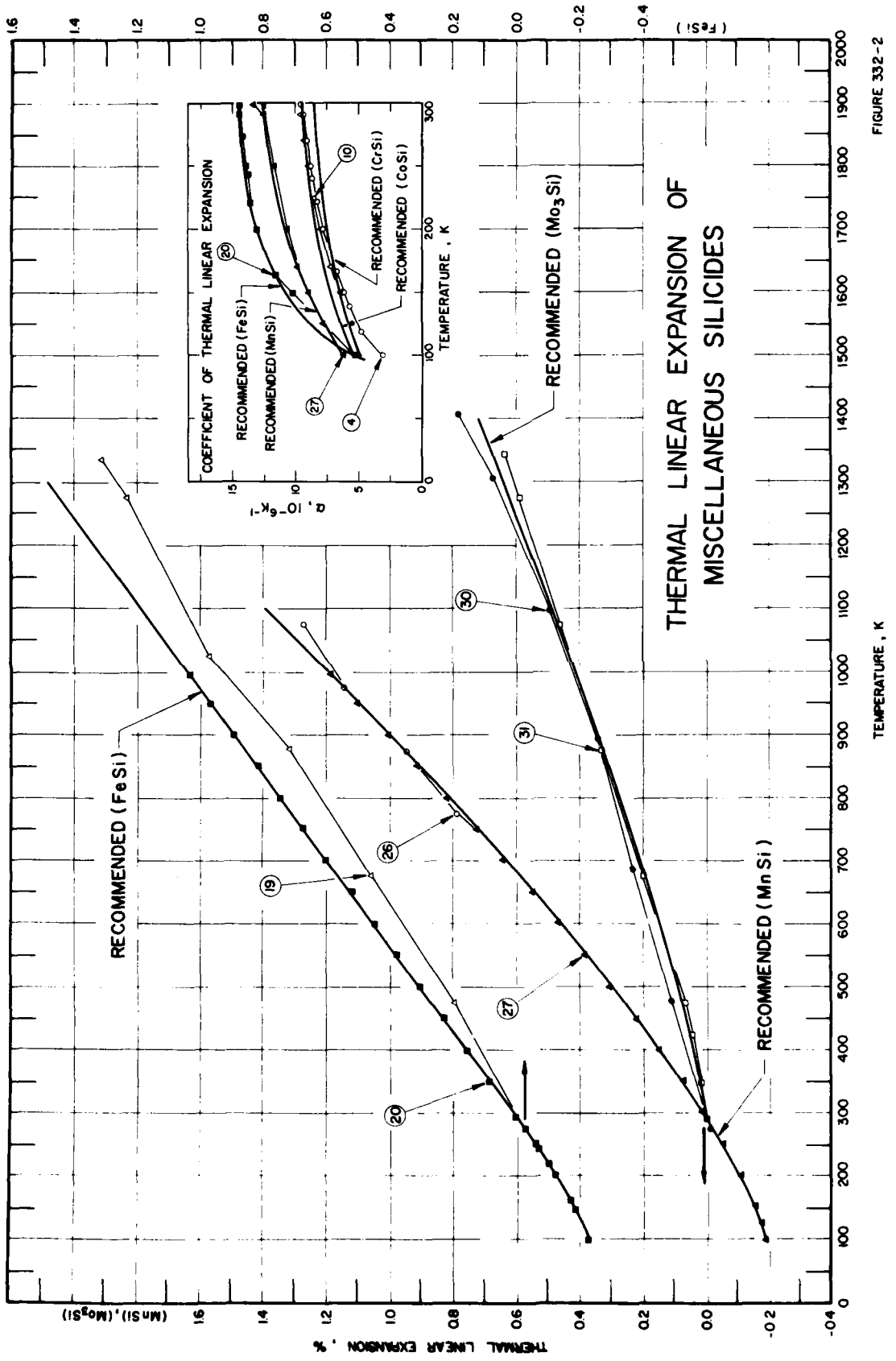

THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICIDES
RECOMMENDED (FeSi)
RECOMMENDED (Mo3Si)
RECOMMENDED (MnSi)
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED (FeSi)
RECOMMENDED (MnSi)
RECOMMENDED (CrSi)
RECOMMENDED (CoSi)
α, 10⁻⁶K⁻¹
TEMPERATURE, K
THERMAL LINEAR EXPANSION, %
(MnSi), (Mo3Si)
(FeSi)
TEMPERATURE, K

FIGURE 332-2

SPECIFICATION TABLE 332. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICIDES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	884	Neshpor, V. S. and Reznichenko, M. I.	1963		293-1353	$BaSi_2$	Barium silicide; 68.6 Ba, 27.2 total Si; sintered, hot pressed, and annealed; fusion temperature 2123 K.
2	437	Frantsevich, I. N., Zhurakovskii, E. A., and Lyashchenko, A. B.	1967	X	293,1473	CrSi	Chromium silicide; sample prepared from powder by the vacuum sintering of pressed block.
3	884	Neshpor, V. S. and Reznichenko, M. I.	1963		293-1043	CrSi	Chromium silicide; 65.1 Cr, 36.2 total Si (0.6 free); sintered, hot pressed, and annealed; fusion temperature 1818 K.
4	887	Krentsis, R. P.	1970	L	100-990	CrSi	Chromium silicide; cylindrical specimen, 20-50 mm long, made from monocrystalline Si; both components' composition 99.99 Cr, 99.98 Si; melted and placed in 3-4 mm quartz capillary tube, then annealed at 1400 K for 20 hr.
5*	889	Verkhorobin, L. F. and Matyushenko, N. N.	1963	X	293,873	$CrSi_2$	Chromium disilicide; synthesized from electrolytic Cr and 99.9 pure Si powder in argon atmosphere at 1100-1150 C for 1 hr; expansion of a-axis; reported error ±7%.
6*	889	Verkhorobin, L. F. and Matyushenko, N. N.	1963	X	293,873	$CrSi_2$	Chromium disilicide; the above specimen; expansion of c-axis; reported error ±9%.
7*	884	Neshpor, V. S. and Reznichenko, M. I.	1963		293-1333	Cr_3Si_2	Trichromium disilicide; 73.8 Cr, 26.9 total Si (0.5 free); sintered, hot pressed, and annealed; fusion temperature 1833 K.
8	885	Zhurovlen, N. N. and Stepanova, A. A.	1962	X	293-1073	CoSi	Cobalt silicide; no details given.
9	886	Kulin, S. A., Peter, E. T., Clougherty, E. V., and Kredor, K.	1970	L	293,1273	CoSi	Cobalt silicide; single crystal; expansion measured in argon atmosphere.
10	887	Krentsis, R. P.	1970	L	100-993	CoSi	Cobalt silicide; dimension cylindrical 20-50 mm long made from monocrystalline 99.99 Si, and elemental 99.89 Co, both elements melted and placed in 3-4 mm quartz capillary tube, then annealed at 1400 K for 20 hr.
11	888	Shashkov, D. P.	1970	L	293-1428	CoSi	Cobalt silicide; monocrystal, melted in pure He by L. D. Dudkin and B. K. Voronov; constituent purity was 99.999 Co, 99.999 Si formed into a single crystal, then changed to polycrystalline by reheating in argon atmosphere.
12*	884	Neshpor, V. S. and Reznichenko, M. I.	1963		293-1258	Co_3Si	Tricobalt silicide; 86.4 Co, 13.1 total Si; sintered, hot pressed, and annealed; fusion temperature 1483 K.
13	891	Novikov, I. I. and Shashkov, D. P.	1966	L	385-996	Cu_5Si	Pentacopper silicide; 91.4 Cu, 8.6 Si (99.95 pure Cu and 99.5 pure Si); smelted and poured in air in metal mold, melting point 1003 K; zero-point correction is 0.001% at 293 K.
14	892	Shashkov, D. P. and Novikov, I. I.	1968	L	293-982	Cu_5Si	Pentacopper silicide; 99.95 purity of Cu, 99.5 purity of Si.
15	892	Shashkov, D. P. and Novikov, I. I.	1968	L	316-979	Cu_5Si	Pentacopper silicide; 99.95 purity of Cu, 99.5 purity of Si, 99.99 purity Al, 99.92 Cu_5 Si melted with Al addition (1.0 at.% Al) in graphite crucible in Tamman furnace with graphite beater.
16	892	Shashkov, D. P. and Novikov, I. I.	1968	L	335-929	Cu_5Si	Pentacopper silicide; similar to the above specimen except alloying of 0.5 at.% of Ce.
17	892	Shashkov, D. P. and Novikov, I. I.	1968	L	293-978	Cu_5Si	Pentacopper silicide; similar to the above specimen except alloying of 1.0 at.% Be.

* Not shown in figure.

SPECIFICATION TABLE 332. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICIDES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
18*	893	Mukherjee, K. P., Bandyopadnaya, J., and Gupta, K. P.	1969	X	296-1021	ϵ-$Cu_{15}Si_4$	Quindecicopper tetrasilicide; 99.99 Cu and 99.9 Si, induction melted and sealed in evacuated quartz capsules; annealed 3 days at 973 K and water quenched; annealed 10 days at 823 K; single ϵ-phase of complex cubic structure apparent in x-ray analysis; author observed a transformation near 873 K of the cubic "ϵ" structure to a form which was not b. c. c.; lattice parameter reported at 296 K as 9.500 Å; 9.500 Å at 293 K determined by graphical interpolation.
19	884	Neshpor, V. S. and Reznichenko, M. I.	1963		293-1333	FeSi	Iron silicide; 66.3 Fe, 33.1 total Si, sintered, hot pressed, and annealed; fusion temperature 1683 K.
20	887	Krentsis, R. P.	1970	L	100-994	FeSi	Iron silicide; dimension: cylindrical 20-50 mm long; made from monocrystalline Si, both elements 99.95 Fe, 99.99 Si melted and placed in 3-4 mm quartz capillary tube; then annealed at 1400 K for 20 hr.
21*	884	Neshpor, V. S. and Reznichenko, M. I.	1963		293-1363	$FeSi_2$	Iron disilicide; 50.9 Fe, 50.8 total Si; sintered, hot pressed, and annealed; fusion temperature 1483 K.
22*	884	Neshpor, V. S. and Reznichenko, M. I.	1963		293-1343	Fe_3Si	Iron (III) silicide; 84.6 Fe, 14.2 total Si (0.3 free); sintered, hot pressed, and annealed; fusion temperature 1573 K.
23*	884	Neshpor, V. S. and Reznichenko, M. I.	1963		293-1338	$LaSi_2$	Lanthanum silicide; 70.95 La, 27.0 total Si (0.06 free); sintered, hot pressed, and annealed; fusion temperature 1793 K.
24*	890	Samsonov, G. V., Neshpor, V. S., and Paderno, Yu. B.	1964		293,843	$LaSi_2$	Lanthanum silicide; mixture of silicon powder and silicon oxide reacted; powders pressed in briquette.
25*	901	Novikova, S. I.	1969	L	24-290	Mg_2Si	Magnesium silicide; polycrystalline specimen prepared from 99.998 pure Mg and Si having carrier concentration $\sim 10^{14}$ cm^{-3}; data compiled from five series of experiments.
26	885	Zhuravlev, N. N. and Stepanova, A. A.	1962	X	293-1073	MnSi	Manganese silicide; no details given.
27	887	Krentsis, R. P.	1970	L	100-994	MnSi	Manganese silicide; dimension: cylindrical 20-50 mm long made from monocrystalline Si, both elements (99.95 Mn, 99.99 Si) and placed in 3-4 mm quartz capillary tube, then annealed at 1400 K for 20 hr.
28*	~~1000~~ 894	Fawcett, E., Malta, J. P., and Wernick, J. H.	1970	E	3-38	MnSi	Manganese silicide; single crystal prepared along a <100> direction by the Czolchralski technique.
29*	437	Frantsevich, I. N., Zhurakovskii, E. A., and Lyashchenko, A. B.	1967	X	293,1423	$MoSi_3$	Molybdenum trisilicide; 64.4 Mo, 35.9 Si, and 36.9 theoretical content of metalloid; sample prepared from powder compound by the vacuum sintering of pressed block.
30	10	Mauer, F. A. and Bolz, L. H.	1957	X	273-1406	Mo_3Si	Trimolybdenum silicide; prepared by R. F. Walker at NBS from 99.7 Si and 99.9 Mo; sintered 2 hr at 1473 K in vacuum; expansion measured in vacuum.
31	884	Neshpor, V. S. and Reznichenko, M. I.	1963		293-1343	Mo_3Si	Trimolybdenum silicide; 90.0 Mo, 8.9 total Si (0.4 free); sintered, hot pressed, and annealed; fusion temperature 2323 K.
32*	884	Neshpor, V. S. and Reznichenko, M. I.	1963		293-1353	Mo_5Si_3	Pentamolybdenum trisilicide; 85.1 Mo, 14.8 total Si (0.8 free), sintered, hot pressed, and annealed; fusion temperature 2373 K.
33*	884	Neshpor, V. S. and Reznichenko, M. I.	1963		293-1353	Ni_2Si	Dinickel silicide; 80.8 Ni, 19.1 total Si; sintered, hot pressed, and annealed; fusion temperature 1563 K.

* Not shown in figure.

SPECIFICATION TABLE 332. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICIDES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
34*	884	Neshpor, V.S. and Reznichenko, M.I.	1963		293-1343	$NbSi_2$	Niobium disilicide; 63.8 Nb, 36.9 total Si (0.4 free); sintered, hot pressed, and annealed; fusion temperature 2233 K.
35*	889	Verkhorobin, L.E. and Matyushenko, N.N.	1963	X	293-1293	$NbSi_2$	Niobium disilicide; commercial-purity Nb; 10 x 10 mm plate annealed in vacuum in 99.9 pure Si powder at 1473-1573 K, 100 μ thick of $NbSi_2$ layer formed; expansion measured from 414 reflection; reported error ±6%.
36*	889	Verkhorobin, L.E. and Matyushenko, N.N.	1963	X	293-1293	$NbSi_2$	Niobium disilicide; the above specimen; expansion measured from 420 reflection.
37*	439	Nowotny, H.	1961		293,923	Nb_5Si_3	Pentaniobium trisilicide; expansion measured parallel to the a-axis direction.
38*	439	Nowotny, H.	1961		293,923	Nb_5Si_3	Pentaniobium trisilicide; expansion measured parallel to the c-axis direction.
39*	884	Neshpor, V.S. and Reznichenko, M.I.	1963		293-1343	ReSi	Rhenium silicide; sintered, hot pressed, and annealed; fusion temperature 2173 K.
40*	884	Neshpor, V.S. and Reznichenko, M.I.	1963		293-1343	$ReSi_2$	Rhenium disilicide; 76.3 Re, 23.8 total Si (0.7 free); sintered, hot pressed, and annealed; fusion temperature 2253 K.
41*	884	Neshpor, V.S. and Reznichenko, M.I.	1963		293-1343	Ti_5Si_3	Pentatitanium trisilicide; 73.0 Ti, 26.8 total Si (0.5 free); sintered, hot pressed, and annealed; fusion temperature 2393 K.
42*	437	Frantsevich, I.N., Zhurakovskii, E.A., and Lyashchenko, A.B.	1967	X	293,1473	$TiSi_2$	Titanium disilicide; 53.4 Si, 46.3 Ti, and 53.9 theoretical content of metalloid; sample prepared from powder by the vacuum sintering of pressed block.
43*	884	Neshpor, V.S. and Reznichenko, M.I.	1963		293-1343	$TiSi_2$	Titanium disilicide; 46.4 Ti, 53.9 total Si (0.6 free); sintered, hot pressed, and annealed; fusion temperature 1813 K.
44*	884	Neshpor, V.S. and Reznichenko, M.I.	1963		293-1349	TiSi	Titanium silicide; 62.8 Ti, 36.8 total Si (0.3 free); sintered, hot pressed, and annealed; fusion temperature 2033 K.
45*	898	Loch, L.D., Engle, G.B., Snyder, M.J., and Duckworth,	1956		293-1023	U_3Si	Triuranium silicide; as cast ingot epsilonized 160 hr at 1073 K.
46*	734	Taylor, K.M. and McMurthy, C.H.	1961		298-1503	U_3Si_2	Triuranium disilicide; 0.62 cm x 1.27 cm x 8.22 cm long; cold pressed and sintered; measured in argon atmosphere.
47*	899	Accary, A. and Coillat, R.	1962		273-1423	U_3Si_2	Triuranium disilicide; cold pressed compact of uranium and silicon with a composition corresponding to U_3Si_2; heating rate 150 K/hr; cooling curve included; transformed into a porous body at about 1273 K; zero-point correction is -0.001% at 293 K.
48*	899	Accary, A. and Coillat, R.	1962		1423-293	U_3Si_2	Triuranium disilicide; powder compact of U_3Si_2; heated in vacuum with a heating rate of 150 K/hr; expansion given in decreasing temperatures; zero-point correction is -0.116% at 293 K.
49*	898	Loch, L.D., Engle, G.B., Snyder, M.J., and Duckworth, W.H.	1956		293-1223	U_3Si_2	Triuranium disilicide; powder sintered 15 hr at 1673 K in argon atmosphere.
50*	900	Beckman, G. and Kiessling, R.	1956	X	298,478	β-USi_2	β-Uranium disilicide; expansion measured in direction of a-axis.
51*	900	Beckman, G. and Kiessling, R.	1956	X	298,478	β-USi_2	β-Uranium disilicide; the above specimen; expansion measured along c-axis.
52*	900	Beckman, G. and Kiessling, R.	1956	X	298,478	β-USi_2	β-Uranium disilicide; the above specimen; expansion measured in direction of U-Si bond.

* Not shown in figure.

SPECIFICATION TABLE 332. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICIDES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
53*	884	Neshpor, V.S. and Reznichenko, M.I.	1963		293-1343	V_3Si	Trivanadium silicide; 83.6 V, 15.9 total Si; sintered, hot pressed, and annealed; fusion temperature 2003 K.
54*	1113 ~~001~~	Fawcett, E.	1971	L	4-30	V_3Si-A	Trivanadium silicide; dimension: rod 10 mm diameter x 10 mm long; expansion measured along a-axis; this curve is here reported using 4 K as reference temperature at which $\Delta L/L_0 = 0$.
55*	1113 ~~001~~	Fawcett, E.	1971	L	4-30	V_3Si-B	Trivanadium silicide; the above specimen, cooling with expansion measured along a-axis; this curve is here reported using 4 K as reference temperature at which $\Delta L/L_0 = 0$.
56*	1113 ~~001~~	Fawcett, E.	1971	L	2-34	V_3Si-B	Trivanadium silicide; dimension: rectangular, 6 mm x 6 mm x 9 mm long; expansion measured along a-axis; this curve is here reported using 2 K as reference temperature at which $\Delta L/L_0 = 0$.
57*	1113 ~~001~~	Fawcett, E.	1971	L	4-17.6	V_3Si	Trivanadium silicide; same as the above specimen except expansion measured along <011> plane; this curve is here reported using 4 K as reference temperature at which $\Delta L/L_0 = 0$.
58*	884	Neshpor, V.S. and Reznichenko, M.I.	1963		293-1343	VSi_2	Vanadium disilicide; 51.2 Si (combined), 47.6 V, 0.3 Si (free); sintered, hot pressed, and annealed; fusion temperature 1943 K.
59*	889	Verkhorobin, L.F. and Matyushenko, N.N.	1963	X	293,1113	VSi_2	Vanadium disilicide; commercial purity V, 10 x 10 mm plate annealed in vacuum in 99.9 pure Si powder at 1473-1573 K, VSi_2 layer of 100 μ thick formed; expansion measured from 114 reflection; reported error ±7%.
60*	889	Verkhorobin, L.F. and Matyushenko, N.N.	1963	X	293,1113	VSi_2	Vanadium disilicide; the above specimen; expansion measured from 301 reflection.
61*	884	Neshpor, V.S. and Reznichenko, M.I.	1963		293-1323	V_5Si_3	Pentavanadium trisilicide; 74.4 V, 25.2 total Si; sintered, hot pressed, and annealed; fusion temperature 2423 K.
62*	437	Frantsevich, I.N., Zhurakovskii, E.A., and Lyashchenko, A.B.	1967	X	293,1473	$ZrSi_2$	Zirconium disilicide; 61.2 Zr, 37.9 Si, and 38.0 theoretical content of metalloid; sample prepared from powder of compound by the vacuum sintering of pressed block.
63*	884	Neshpor, V.S. and Reznichenko, M.I.	1963		293-1343	$ZrSi_2$	Zirconium disilicide; 61.2 Zr, 38.5 total Si (0.7 free); sintered, hot pressed, and annealed; fusion temperature 2233 K.

* Not shown in figure.

DATA TABLE 332. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
353	0.015
473	0.103
673	0.260
873	0.423
1073	0.589
1273	0.746
1353	0.807
CURVE 2	
293	0.000
1473	1.062
CURVE 3	
293	0.000
348	0.021
473	0.165
673	0.395
873	0.627
1043	0.827
CURVE 4‡	
100	-0.141
118	-0.133
138	-0.123
150	-0.116
166	-0.106
200	-0.081
222	-0.063
240	-0.048
250	-0.039
271	-0.021
293	0.000
300	0.007
335	0.041
350	0.056
400	0.107
450	0.160
500	0.215
550	0.271
600	0.328
650	0.386
700	0.446

T	$\Delta L/L_0$
CURVE 4 (cont.)‡	
750	0.507
800	0.569
850	0.633
900	0.698
950	0.764
990	0.818
CURVE 5*	
293	0.00
873	0.56
CURVE 6*	
293	0.00
873	0.47
CURVE 7*	
293	0.000
348	0.021
473	0.125
673	0.352
873	0.580
1073	0.840
1273	1.135
1333	1.222
CURVE 8	
293	0.000
773	0.540
873	0.652
973	0.742
1073	0.877
CURVE 9	
293	0.000
1273	1.176
CURVE 10‡	
100	-0.145
118	-0.138
138	-0.127

T	$\Delta L/L_0$
CURVE 10 (cont.)‡	
150	-0.120
170	-0.106
200	-0.083
224	-0.063
250	-0.040
271	-0.021
293	0.000
300	0.007
335	0.041
350	0.057
400	0.109
450	0.164
500	0.220
550	0.278
600	0.337
650	0.398
700	0.460
750	0.523
800	0.588
850	0.653
900	0.721
950	0.789
993	0.849
CURVE 11‡	
293	0.000
373	0.085
473	0.198
573	0.319
673	0.448
773	0.585
873	0.727
973	0.874
1073	1.027
1118	1.097
1153	1.158
1173	1.197
1213	1.288
1223	1.312
1243	1.357
1263	1.393
1273	1.407
1373	1.537
1428	1.611

T	$\Delta L/L_0$
CURVE 12*	
293	0.000
343	0.055
473	0.229
673	0.483
873	0.770
1073	1.115
1258	1.400
CURVE 13‡	
385	0.160
443	0.266
485	0.344
535	0.440
586	0.541
653	0.678
719	0.817
760	0.906
790	0.972
848	1.101
886	1.188
949	1.333
996	1.444
CURVE 14‡	
293	0.000
372	0.137
474	0.324
527	0.426
574	0.518
628	0.627
675	0.725
733	0.849
780	0.952
808	1.015
829	1.062
880	1.177
934	1.302
982	1.415
CURVE 15†	
316	0.000
374	0.001
428	0.002
473	0.003

T	$\Delta L/L_0$
CURVE 15 (cont.)‡	
528	0.405
578	0.500
622	0.587
674	0.692
728	0.804
778	0.911
831	1.027
875	1.124
935	1.260
979	1.362
CURVE 16‡	
335	0.066
371	0.125
428	0.220
478	0.307
527	0.394
579	0.490
634	0.595
680	0.685
732	0.790
759	0.846
783	0.895
833	1.000
880	1.101
929	1.208
CURVE 17‡	
293	0.000
373	0.135
423	0.223
474	0.315
522	0.406
576	0.511
630	0.619
674	0.710
729	0.828
778	0.935
828	1.048
874	1.154
931	1.287
978	1.398

T	$\Delta L/L_0$
CURVE 18*	
296	0.000
701	0.515
771	0.547
817	0.736
876	0.957
910	0.842
958	0.789
997	0.684
1021	0.652
CURVE 19	
293	0.000
343	0.045
473	0.195
673	0.460
873	0.720
1073	0.975
1273	1.240
1333	1.320
CURVE 20‡	
100	-0.227
150	-0.188
164	-0.173
200	-0.129
221	-0.101
244	-0.069
250	-0.061
274	-0.027
293	0.000
300	0.010
350	0.082
400	0.155
450	0.227
500	0.300
550	0.372
600	0.446
650	0.519
700	0.593
750	0.667
800	0.742
850	0.817
900	0.892
950	0.969
994	1.036

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 332. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICIDES (continued)

T	$\Delta L/L_0$
CURVE 21*	
293	0.000
348	0.018
473	0.107
673	0.247
873	0.374
1073	0.510
1273	0.650
1363	0.707
CURVE 22*	
293	0.000
353	0.015
443	0.050
473	0.070
498	0.093
623	0.270
673	0.350
873	0.636
1073	0.934
1123	1.000
1153	1.050
1193	1.083
1235	1.102
1273	1.122
1343	1.132
CURVE 23*	
293	0.000
343	0.037
473	0.125
673	0.290
873	0.458
1073	0.673
1273	0.898
1338	0.972
CURVE 24*	
293	0.0000
843	0.4218
CURVE 25*,‡	
24.4	-0.242
32.8	-0.242
42.8	-0.241

T	$\Delta L/L_0$
CURVE 25 (cont.)*,‡	
52.3	-0.241
61.5	-0.239
70.9	-0.237
83.4	-0.232
86.6	-0.230
91.7	-0.228
96.4	-0.226
99.0	-0.224
106.2	-0.220
110.9	-0.217
114.6	-0.214
122.2	-0.209
122.8	-0.208
129.8	-0.203
133.2	-0.200
137.5	-0.197
145.4	-0.189
145.7	-0.189
152.9	-0.182
156.7	-0.178
156.7	-0.178
161.0	-0.173
163.8	-0.170
163.9	-0.170
167.4	-0.166
169.0	-0.164
171.5	-0.162
174.7	-0.158
179.0	-0.153
179.9	-0.152
185.1	-0.146
187.9	-0.142
193.0	-0.136
195.5	-0.133
202.8	-0.124
207.1	-0.118
207.1	-0.118
212.3	-0.112
217.7	-0.104
217.7	-0.104
230.6	-0.087
237.3	-0.078
241.4	-0.072
245.5	-0.067
249.5	-0.061
256.2	-0.052
262.0	-0.044
275.8	-0.024
290.7	-0.004

T	$\Delta L/L_0$
CURVE 26	
293	0.000
773	0.790
873	0.943
973	1.141
1073	1.272
CURVE 27‡	
100	-0.195
126	-0.177
150	-0.157
170	-0.138
200	-0.108
250	-0.052
293	0.000
300	0.009
350	0.078
400	0.150
450	0.225
500	0.303
550	0.383
600	0.466
650	0.551
700	0.638
750	0.728
800	0.819
850	0.913
900	1.008
950	1.104
994	1.189
CURVE 28*,†,‡	
3.6	0.000×10^{-2}
5.0	-0.003
6.3	-0.006
7.6	-0.010
8.6	-0.014
9.6	-0.019
10.9	-0.024
11.7	-0.029
12.6	-0.034
13.7	-0.041
14.7	-0.047
15.7	-0.054
16.6	-0.061
17.8	-0.070
18.8	-0.079

T	$\Delta L/L_0$
CURVE 28 (cont.)*,†,‡	
19.7	-0.087×10^{-2}
20.8	-0.099
21.8	-0.110
22.8	-0.123
23.9	-0.139
24.9	-0.158
25.9	-0.180
26.4	-0.193
27.0	-0.211
27.4	-0.225
27.9	-0.247
28.1	-0.258
28.2	-0.264
28.3	-0.271
28.4	-0.277
28.6	-0.293
28.7	-0.300
28.8	-0.309
28.9	-0.318
28.9	-0.318
28.9	-0.318
29.1	-0.334
29.1	-0.334
29.3	-0.348
29.4	-0.355
29.5	-0.361
29.6	-0.367
29.7	-0.373
29.8	-0.378
29.8	-0.378
29.9	-0.383
29.9	-0.383
31.0	-0.406
31.8	-0.411
31.9	-0.411
32.9	-0.403
33.9	-0.387
34.9	-0.369
35.8	-0.350
36.8	-0.326
37.9	-0.296
CURVE 29*	
293	0.000
1473	0.944

T	$\Delta L/L_0$
CURVE 30	
273	-0.011
298	0.003
479	0.108
685	0.233
891	0.348
1097	0.495
1303	0.677
1406	0.786
CURVE 31	
293	0.000
343	0.016
423	0.045
473	0.070
673	0.206
873	0.333
1073	0.460
1273	0.590
1343	0.638
CURVE 32*	
293	0.000
343	0.030
473	0.116
673	0.250
873	0.380
1073	0.517
1273	0.650
1353	0.701
CURVE 33*	
293	0.000
353	0.054
473	0.158
643	0.305
673	0.347
873	0.578
1073	0.796
1113	0.843
1273	1.095
1353	1.220
CURVE 34*	
293	0.000

T	$\Delta L/L_0$
CURVE 34 (cont.)	
343	0.061
473	0.160
673	0.325
873	0.565
1073	0.810
1273	1.040
1343	1.270
CURVE 35*	
293	0.00
1293	0.74
CURVE 36*	
293	0.00
1293	0.72
CURVE 37*	
293	0.00
923	0.46
CURVE 38*	
293	0.000
923	0.286
CURVE 39*	
293	0.000
353	0.025
473	0.050
498	0.057
673	0.140
873	0.240
1073	0.349
1273	0.438
1343	0.470
CURVE 40*	
293	0.000
343	0.010
473	0.055
673	0.170
873	0.305
1073	0.445

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 332. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICIDES (continued)

T	$\Delta L/L_0$
CURVE 40 (cont.)*	
1273	0.582
1343	0.625
CURVE 41*	
293	0.000
348	0.021
473	0.081
673	0.295
873	0.520
1073	0.740
1273	0.968
1343	1.046
CURVE 42*	
293	0.000
1473	1.475
CURVE 43*	
293	0.000
343	0.050
473	0.184
673	0.401
873	0.610
1073	0.821
1273	1.040
1343	1.140
CURVE 44*	
293	0.000
344	0.050
473	0.150
643	0.305
673	0.325
873	0.530
1073	0.740
1273	0.949
1349	1.029
CURVE 45*	
293	0.000
473	0.234
573	0.375
673	0.540
773	0.715
873	0.916
973	1.142
1023	1.278
CURVE 46*	
298	0.005
503	0.280
512	0.296
513	0.285
709	0.580
911	0.879
1111	1.181
1112	1.203
1113	1.192
1309	1.513
1306	1.491
1501	1.780
1503	1.815
CURVE 47*	
273	0.000
293	0.000
323	0.003
373	0.005
423	0.007
473	0.007
523	0.007
573	0.008
623	0.009
673	0.011
723	0.030
773	0.077
823	0.105
873	0.105
923	0.096
973	0.090
1023	0.101
1073	0.116
1123	0.126
1173	0.134
1223	0.138
1273	0.155
1323	0.167
1373	0.173
1423	0.173
CURVE 48*	
1423	0.055
1373	0.052
1323	^ 051
1273	0.049
1223	0.045
1173	0.042
1123	0.039
1073	0.036
1023	0.033
973	0.031
923	0.028
873	0.025
823	0.023
773	0.020
723	0.018
673	0.016
623	0.014
573	0.011
523	0.009
473	0.007
423	0.005
373	0.004
323	0.00?
293	0.000
CURVE 49*	
293	0.000
473	0.279
573	0.428
673	0.578
773	0.734
873	0.882
973	1.027
1073	1.170
1173	1.294
1223	1.358
CURVE 50*	
298	0.0285
478	1.055
CURVE 51*	
298	0.013
478	-0.481
CURVE 52*	
298	0.008
478	0.296
CURVE 53*	
293	0.000
343	0.012
473	0.120
673	0.292
873	0.464
1073	0.660
1273	0.940
1343	1.040
CURVE 54*, †, ‡	
4.0	0.000000
4.7	0.000021
5.1	0.000045
5.6	0.000075
6.3	0.000117
7.0	0.000159
7.8	0.000207
8.4	0.000243
9.2	0.000291
9.7	0.000321
10.6	0.000375
11.1	0.000415
11.6	0.000470
12.8	0.000575
13.5	0.000665
14.1	0.000826
14.9	0.00100
15.4	0.00131
15.8	0.00156
16.0	0.00178
16.3	0.00191
16.6	0.00213
17.0	0.00241
17.3	0.00293
17.6	0.00345
18.0	0.00412
18.3	0.00534
18.7	0.00628
19.2	0.00798
19.7	0.0109
20.0	0.0137
21.1	0.0159
22.1	0.0266
23.1	0.0391
24.1	0.0534
25.0	0.0683
26.1	0.0833
27.0	0.101
28.0	0.117
28.9	0.134
30.0	0.150
CURVE 55*, †, ‡	
4.0	0.000000
11.3	0.000175
11.7	0.000194
12.3	0.000229
13.0	0.000278
13.5	0.000322
14.2	0.000397
15.0	0.000502
15.4	0.000561
16.0	0.000672
16.3	0.000781
16.4	0.000843
16.7	0.00111
17.1	0.00159
17.4	0.00202
17.7	0.00249
18.1	0.00318
18.5	0.00394
18.9	0.00481
19.3	0.00582
19.6	0.00666
20.0	0.00788
21.0	0.0108
22.0	0.0131
23.1	0.0149
24.0	0.0158
25.1	0.0166
26.0	0.0170
27.0	0.0174
28.1	0.0177
30.0	0.0181
CURVE 56*, †, ‡	
2.0	0.000×10^{-5}
2.4	-0.002
2.7	-0.005×10^{-5}
3.2	-0.010
3.6	-0.015
4.0	-0.024
4.3	-0.033
4.6	-0.042
5.3	-0.072
5.6	-0.087
6.1	-0.116
7.1	-0.178
8.1	-0.240
8.7	-0.275
9.2	-0.300
9.8	-0.324
10.3	-0.338
10.7	-0.343
11.2	-0.342
11.6	-0.335
12.2	-0.308
12.8	-0.265
13.1	-0.237
13.4	-0.202
13.7	-0.162
13.9	-0.132
14.3	-0.063
14.7	0.018
14.9	0.064
15.3	0.168
15.7	0.279
15.8	0.307
16.0	0.357
16.1	0.379
16.1	0.379
16.4	0.429
16.5	0.442
16.6	0.452
16.9	0.469
17.2	0.475
17.3	0.472
17.7	0.443
18.1	0.393
18.7	0.285
19.3	0.133
19.7	-0.005
20.9	-0.537
21.9	-1.057
22.8	-1.583
23.7	-2.160

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 332. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICIDES (continued)

T	$\Delta L/L_0$
CURVE 56 (cont.)*,†,‡	
24.8	-2.914×10^{-5}
25.7	-3.560
26.7	-4.299
27.9	-5.205
28.7	-5.815
29.7	-6.568
30.9	-7.451
31.7	-8.022
32.8	-8.771
33.7	-9.343
CURVE 57*,†,‡	
4.0	0.000×10^{-3}
4.9	0.002
5.4	0.005
5.9	0.007
6.3	0.010
6.7	0.012
7.3	0.018
7.7	0.022
8.3	0.030
8.7	0.037
9.4	0.051
9.9	0.062
10.2	0.071
10.7	0.086
11.2	0.105
11.7	0.125
12.3	0.154
12.9	0.187
13.2	0.207
13.9	0.258
14.0	0.266
14.2	0.283
14.5	0.309
14.7	0.328
14.9	0.348
15.1	0.369
15.3	0.392
15.6	0.427
15.9	0.463
16.2	0.502
16.4	0.528
16.6	0.556
16.8	0.584
17.2	0.643
17.6	0.704

T	$\Delta L/L_0$
CURVE 58*	
293	0.000
343	0.061
473	0.199
673	0.420
873	0.640
1073	0.880
1273	1.165
1343	1.275
CURVE 59*	
293	0.00
1113	0.93
CURVE 60*	
293	0.00
1113	0.85
CURVE 61*	
293	0.000
333	0.046
473	0.173
673	0.365
873	0.555
1073	0.750
1273	0.973
1323	1.034
CURVE 62*	
293	0.000
1473	0.861
CURVE 63*	
293	0.000
348	0.038
473	0.129
673	0.303
873	0.480
1073	0.667
1273	0.841
1343	0.900

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 332. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICIDES

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

CURVE 4‡

T	α
100	3.16
118	4.77
138	5.69
150	6.10
166	6.70
200	7.74
222	8.31
240	8.68
250	8.84
271	9.17
293	9.47
300	9.60
335	9.94
350	10.06
400	10.38
450	10.78
500	11.10
550	11.30
600	11.53
650	11.79
700	12.13
750	12.33
800	12.59
850	12.87
900	13.11
950	13.35
990	13.52

CURVE 10‡

T	α
100	3.16
118	4.77
138	5.96
150	6.48
170	7.16
200	7.99
224	8.57
250	9.10
271	9.43
293	9.66
300	9.70
335	10.14
350	10.29
400	10.69
450	11.14
500	11.46

CURVE 10 (cont.)‡

T	α
550	11.68
600	11.96
605	12.26
700	12.51
750	12.77
800	13.08
850	13.28
900	13.56
950	13.84
993	14.02

CURVE 11*,‡

T	α
293	10.31
373	10.90
473	11.73
573	12.44
673	13.37
773	14.00
873	14.39
973	15.04
1073	15.52
1118	15.70
1153	18.95
1173	20.95
1213	24.20
1223	24.49
1243	20.35
1263	15.63
1273	12.6[illegible]
1373	13.30
1428	13.65

CURVE 13*,‡

T	α
385	17.9
443	18.5
485	19.0
535	19.4
586	20.0
653	20.8
719	21.4
760	21.9
790	22.2
848	22.5
886	22.8

CURVE 13 (cont.)*,‡

T	α
949	23.4
996	23.9

CURVE 14*,‡

T	α
293	16.8
372	17.7
474	18.9
527	19.4
574	19.9
628	20.5
675	21.1
733	21.6
780	22.1
808	22.4
829	22.4
880	22.9
934	23.3
982	23.7

CURVE 15*,‡

T	α
316	16.1
374	16.8
428	17.5
473	17.9
528	18.6
578	19.2
622	19.9
674	20.4
728	21.0
778	21.7
831	22.0
875	22.3
935	22.8
979	23.4

CURVE 16*,‡

T	α
335	16.0
371	16.4
428	17.0
478	17.6
527	18.0
579	18.8
634	19.2

CURVE 16 (cont.)*,‡

T	α
680	19.8
732	20.5
759	20.6
783	20.7
833	21.1
880	21.6
929	22.2

CURVE 17*,‡

T	α
293	16.3
373	17.3
423	17.8
474	18.5
522	19.1
576	19.7
630	20.3
674	21.0
729	21.7
778	22.3
828	22.8
874	23.0
931	23.4
978	23.8

CURVE 20‡

T	α
100	5.29
150	10.20
164	11.52
200	13.03
221	13.51
244	13.86
250	13.98
274	14.21
293	14.43
300	14.43
350	14.49
400	14.50
450	14.43
500	14.52
550	14.61
600	14.65
650	14.74
700	14.80
750	14.88

CURVE 20 (cont.)‡

T	α
800	14.97
850	15.09
900	15.16
950	15.29
994	15.42

CURVE 25*,‡

T	α
24.4	0.16
32.8	0.25
42.8	0.57
52.3	0.93
61.5	2.22
70.9	3.34
83.4	4.44
86.6	4.06
91.7	4.92
96.4	5.35
99.0	5.76
106.2	6.47
110.9	6.47
114.6	6.92
122.2	7.79
122.8	7.23
129.8	7.88
133.2	8.75
137.5	8.28
145.4	9.63
145.7	9.20
152.9	10.42
156.7	10.23
156.7	10.84
161.0	11.13
163.8	11.75
163.9	10.51
167.4	11.40
169.0	12.02
171.5	10.98
174.7	11.67
179.0	11.42
179.9	12.12
185.1	12.36
187.9	12.02
193.0	12.65
195.5	12.36
202.8	12.36

CURVE 25 (cont.)*,‡

T	α
207.1	12.55
207.1	12.98
212.3	13.31
217.7	12.76
217.7	13.36
230.6	13.66
237.3	13.81
241.4	13.58
245.5	13.81
249.5	14.11
256.2	14.03
262.0	13.68
275.8	14.13
290.7	13.92

CURVE 27‡

T	α
100	6.14
126	7.81
150	8.91
170	9.83
200	10.59
250	11.69
293	12.51
300	13.35
350	14.03
400	14.77
450	15.30
500	15.84
550	16.35
600	16.79
650	17.22
700	17.66
750	18.11
800	18.55
850	18.87
900	19.19
950	19.28
994	19.51

CURVE 28*,‡

T	α
3.6	-0.176
5.0	-0.240
6.3	-0.302
7.6	-0.365

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 332. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS SILICIDES (continued)

T	α
CURVE 28 (cont.)*,‡	
8.6	-0.413
9.6	-0.461
10.9	-0.523
11.7	-0.550
12.6	-0.580
13.7	-0.617
14.7	-0.662
15.7	-0.707
16.6	-0.764
17.8	-0.819
18.8	-0.902
19.7	-0.985
20.8	-1.102
21.8	-1.199
22.8	-1.345
23.9	-1.625
24.9	-1.992
25.9	-2.590
26.4	-2.614
27.0	-3.078
27.4	-3.973
27.9	-4.910
28.1	-6.294
28.2	-6.599
28.3	-6.254
28.4	-6.844
28.6	-7.522
28.7	-8.438
28.8	-9.130
28.9	-10.462
28.9	-9.537
28.9	-8.179
29.1	-7.857
29.1	-7.071
29.3	-6.827
29.4	-6.556
29.5	-6.284
29.6	-5.802
29.7	-5.405
29.8	-5.126
29.8	-4.798
29.9	-4.246
29.9	-3.020
31.0	-1.209
31.8	0.000
31.9	0.255
32.9	1.316
33.9	1.797

T	α
CURVE 28 (cont.)*,‡	
34.9	1.920
35.8	2.184
36.8	2.613
37.9	2.843
CURVE 54*,‡	
4.0	0.0
4.7	0.6
5.1	0.6
5.6	0.6
6.3	0.6
7.0	0.6
7.8	0.6
8.4	0.6
9.2	0.6
9.7	0.6
10.6	0.6
11.1	1.0
11.6	1.2
12.8	1.8
13.5	2.8
14.1	3.2
14.9	4.6
15.4	5.2
15.8	6.0
16.0	6.8
16.3	7.8
16.6	11.2
17.0	14.8
17.3	19.6
17.6	24.8
18.0	31.4
18.3	38.2
18.7	46.8
19.2	56.2
19.7	69.4
20.0	81.2
21.1	113.4
22.1	136.6
23.1	149.0
24.1	158.4
25.0	164.4
26.1	169.0
27.0	172.8
28.0	176.6
28.9	177.8
30.0	179.8

T	α
CURVE 55*,‡	
4.0	0.00
11.3	0.48
11.7	0.50
12.3	0.64
13.0	0.76
13.5	1.00
14.2	1.16
15.0	1.46
15.4	1.50
16.0	2.18
16.3	5.12
16.4	7.18
16.7	10.96
17.1	13.28
17.4	14.92
17.7	16.42
18.1	18.02
18.5	20.08
18.9	23.52
19.3	26.92
19.6	29.40
20.0	31.58
21.0	26.82
22.0	19.54
23.1	12.74
24.0	8.04
25.1	5.94
26.0	4.18
27.0	3.38
28.1	2.50
30.0	1.12
CURVE 56*,‡	
2.0	-0.006
2.4	-0.006
2.7	-0.010
3.2	-0.010
3.6	-0.018
4.0	-0.026
4.3	-0.030
4.6	-0.036
5.3	-0.048
5.6	-0.054
6.1	-0.062
7.1	-0.062
8.1	-0.062
8.7	-0.054

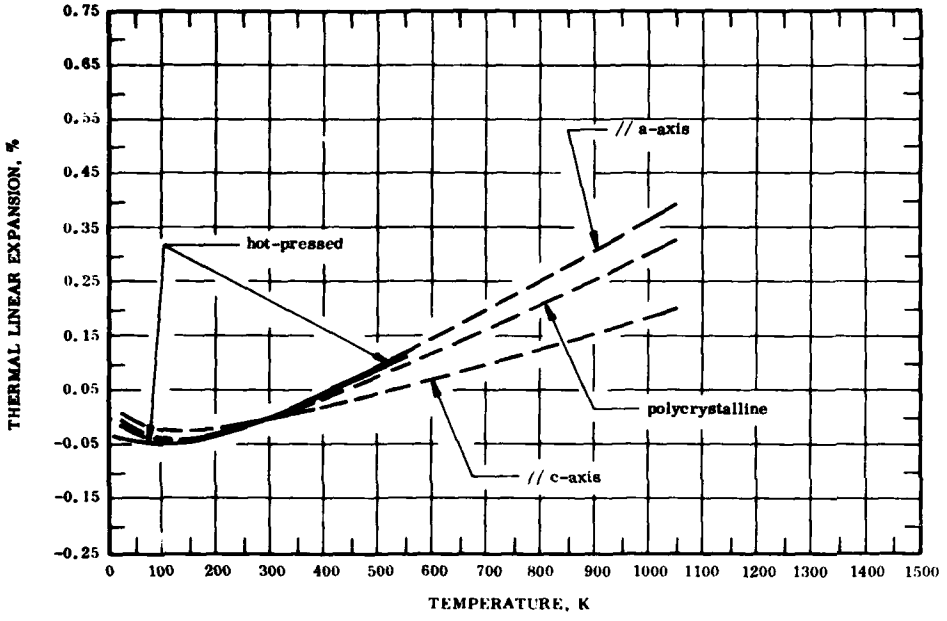
T	α
CURVE 56 (cont.)*,‡	
9.2	-0.046
9.8	-0.034
10.3	-0.024
10.7	0.000
11.2	0.006
11.6	0.028
12.2	0.062
12.8	0.082
13.1	0.106
13.4	0.126
13.7	0.140
13.9	0.158
14.3	0.188
14.7	0.214
14.9	0.252
15.3	0.266
15.7	0.292
15.8	0.266
16.0	0.234
16.1	0.208
16.1	0.186
16.4	0.146
16.5	0.116
16.6	0.076
16.9	0.038
17.2	0.000
17.3	-0.048
17.7	-0.100
18.1	-0.150
18.7	-0.210
19.3	-0.294
19.7	-0.400
20.9	-0.486
21.9	-0.554
22.8	-0.616
23.7	-0.666
24.8	-0.704
25.7	-0.732
26.7	-0.746
27.9	-0.764
28.7	-0.760
29.7	-0.746
30.9	-0.726
31.7	-0.702
32.8	-0.660
33.7	-0.610

T	α
CURVE 57*,‡	
4.0	0.026
4.9	0.038
5.4	0.048
5.9	0.056
6.3	0.066
6.7	0.078
7.3	0.092
7.7	0.126
8.3	0.158
8.7	0.180
9.4	0.210
9.9	0.254
10.2	0.292
10.7	0.338
11.2	0.390
11.7	0.440
12.3	0.516
12.9	0.596
13.2	0.684
13.9	0.776
14.0	0.824
14.2	0.858
14.5	0.916
14.7	0.978
14.9	1.040
15.1	1.082
15.3	1.134
15.6	1.202
15.9	1.252
16.2	1.304
16.4	1.350
16.6	1.402
16.8	1.442
17.2	1.498
17.6	1.540

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 333R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF CADMIUM SULFIDE Cd[illegible]



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	// a-axis	// c-axis	polycrystalline		Hot-Pressed	
T	$\Delta L/L_0$ †	$\Delta L/L_0$ †	$\Delta L/L_0$ †	α	$\Delta L/L_0$	α
10					-0.030	-0.15
25	-0.010	0.010	-0.003		-0.033	-1.45
50	-0.027	-0.005	-0.020		-0.039	-2.6
75	-0.042	-0.018	-0.034		-0.043	-1.7
100	-0.051	-0.027	-0.043	-0.6	-0.044	-0.5
150	-0.049	-0.029	-0.042	1.4	-0.041	1.5
200	-0.034	-0.021	-0.030	2.6	-0.032	2.7
250	-0.017	-0.011	-0.015	3.3	-0.017	3.4
293	0.000	0.000	0.000	3.6	0.000	3.9
300	0.003	0.002	0.003	3.6	0.002	4.0
350	0.025	0.013	0.021	3.8	0.024	4.4
400	0.048	0.025	0.040	3.9	0.047	4.7
450	0.072	0.037	0.060	4.0	0.071	4.9
500	0.096	0.049	0.080	4.2	0.095	5.1
550	0.121	0.062	0.101	4.3	0.117	5.2
600	0.147	0.075	0.123	4.4		
650	0.173	0.089	0.145	4.4		
700	0.200	0.102	0.167	4.5		
750	0.227	0.116	0.190	4.6		
800	0.255	0.130	0.213	4.7		
850	0.283	0.144	0.237	4.7		
900	0.311	0.158	0.260	4.7		
950	0.340	0.173	0.284	4.8		
1000	0.368	0.187	0.308	4.8		
1050	0.397	0.202	0.332	4.9		

† Provisional values.

REMARKS

The recommended values for the hot-pressed sample are based on curves 7 and 8. These values are considered accurate to within ± 5%. The provisional values for polycrystalline samples are calculated from the values for axial thermal linear expansion. An anomaly of unexplained nature is found near 135 K. These values are considered accurate to within ± 7%. The tabulated values for the thermal linear expansion are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.107 + 2.948 \times 10^{-4}\ T + 2.641 \times 10^{-7}\ T^2 - 8.378 \times 10^{-11}\ T^3$ (293-1050 K)

// c-axis: $\Delta L/L_0 = -5.875 \times 10^{-2} + 1.744 \times 10^{-4}\ T + 9.634 \times 10^{-8}\ T^2 - 2.467 \times 10^{-11}\ T^3$ (293-1050 K)

polycrystalline: $\Delta L/L_0 = -9.004 \times 10^{-2} + 2.498 \times 10^{-4}\ T + 2.164 \times 10^{-7}\ T^2 - 6.813 \times 10^{-11}\ T^3$ (293-1050 K)

Hot-Pressed: $\Delta L/L_0 = -2.607 \times 10^{-2} - 3.609 \times 10^{-4}\ T + 1.971 \times 10^{-6}\ T^2 - 1.530 \times 10^{-9}\ T^3$ (50-550 K)

The tabulated values for the coefficient of thermal expansion for polycrystalline sample are primarily derived from the selected experimental data while those for polycrystalline powdered sample are from differentiation of above equation. These values are considered accurate to about ± 7% and ± 10% respectively.

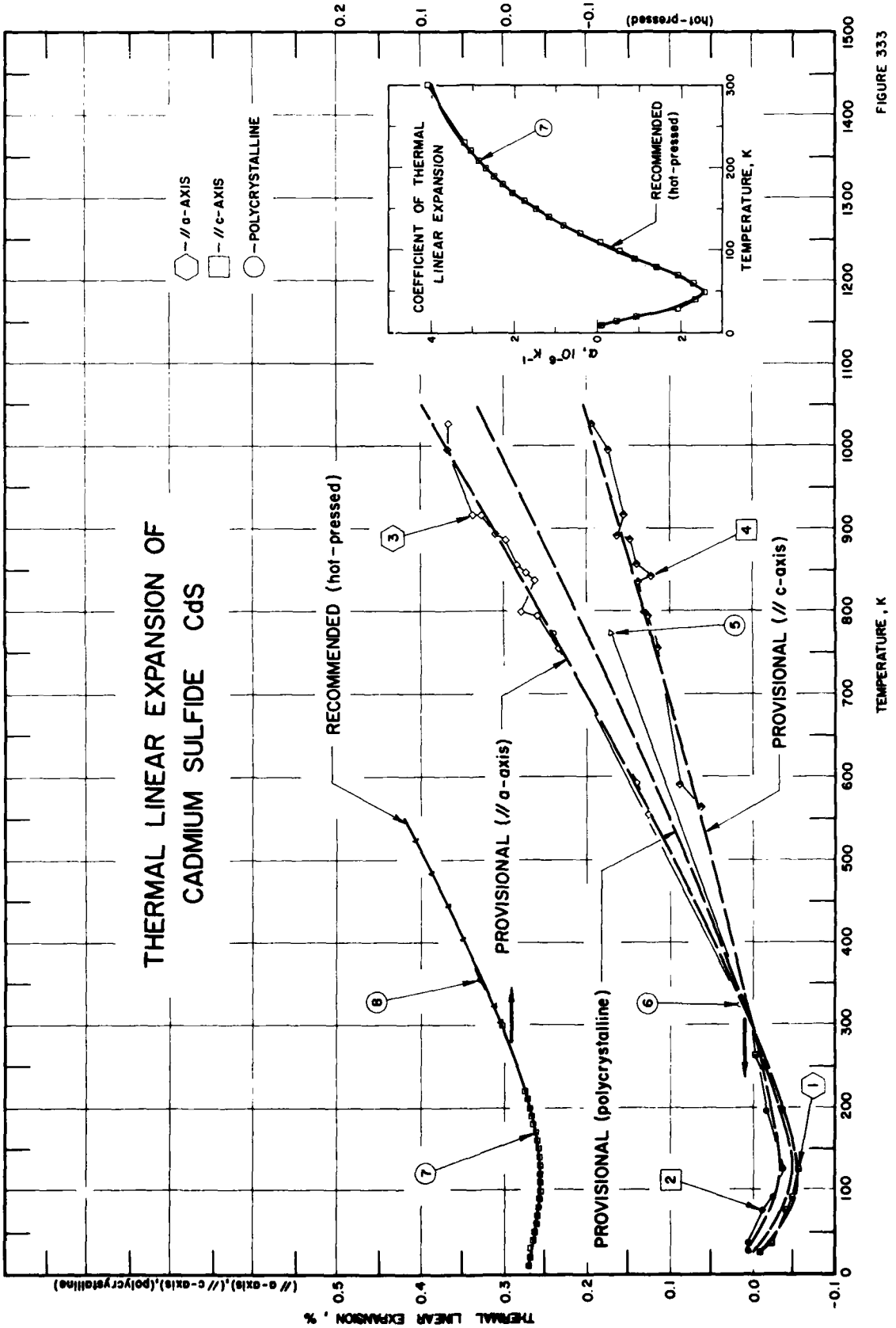

THERMAL LINEAR EXPANSION OF
CADMIUM SULFIDE CdS
// a-AXIS
// c-AXIS
POLYCRYSTALLINE
RECOMMENDED (hot-pressed)
PROVISIONAL (// a-axis)
PROVISIONAL (// c-axis)
PROVISIONAL (polycrystalline)
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED (hot-pressed)
TEMPERATURE, K
TEMPERATURE, K
THERMAL LINEAR EXPANSION, %
(// a-axis), (// c-axis), (polycrystalline)
(hot-pressed)

FIGURE 333

SPECIFICATION TABLE 333. THERMAL LINEAR EXPANSION OF CADMIUM SULFIDE CdS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	902	Reeber, R.R. and Kulp, B.A.	1965	X	26-296	Sample No. 4	Eagle Picher ultra pure CdS used; 1.27 cm I.D. quartz ampoule filled and sealed under vacuum; heat treated at 873 K, 2 weeks, then sieved through 325 mesh screen; pure Si added for reference, mixed with thinned Duco cement, spread in thin layer on flat copper finger in cryostat; expansion measured on a-axis; lattice parameter reported at 296 K as 4.1364 Å; 4.1364 Å at 293 K determined by graphical interpolation.
2	902	Reeber, R.R. and Kulp, B.A.	1965	X	26-296		The above specimen; expansion measured on c-axis; lattice parameter reported at 296 K as 6.7153 Å; 6.7153 Å at 293 K determined by graphical interpolation.
3	902	Reeber, R.R. and Kulp, B.A.	1965	X	293-1028		Eagle Picher ultra pure grade CdS; sealed as received in quartz capillary under vacuum; expansion observed on a-axis; lattice parameter reported at 293 K as 4.1364 Å.
4	902	Reeber, R.R. and Kulp, B.A.	1965	X	293-1028		The above specimen; expansion on c-axis; lattice parameter reported at 293 K as 6.7152 Å.
5	903	Francis, A.B. and Carlson, A.I.	1960	L	323, 773		Single crystal specimen; grown by sublimation; recrystallization method; expansion parallel to principal axis.
6	903	Francis, A.B. and Carlson, A.I.	1960	L	323, 773		The above specimen; expansion perpendicular to axis.
7	904	Browder, J.S. and Ballard, S.S.	1971	E	10-300		Microcrystalline; hot pressed specimen obtained from Eastman Kodak Company of Rochester, New York.
8	905, 906	Ebersole, J.F., Ballard, S.S., and Browder, J.S.	1971	L	303-523		Dimension right circular crystalline 6-8 mm diameter x 12 mm long; microcrystalline; hot pressed compact material, polycrystalline; sample obtained from Eastman Kodak Company of Rochester, New York.

DATA TABLE 333. THERMAL LINEAR EXPANSION OF CADMIUM SULFIDE CdS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
26	-0.007
36	-0.022
77	-0.039
90	-0.046
125	-0.053
195	-0.036
264	-0.002
296	0.000
CURVE 2	
26	0.009
36	0.004
77	-0.012
90	-0.022
125	-0.039
195	-0.019
264	-0.000*
296	-0.000*

T	$\Delta L/L_0$
CURVE 3	
293	0.000
564	0.126
591	0.140
757	0.237
795	0.259
800	0.278
837	0.261
843	0.271
858	0.285
888	0.297
892	0.309
918	0.336
918	0.326
996	0.367
1028	0.367
CURVE 4	
293	0.000*

T	$\Delta L/L_0$
CURVE 4 (cont.)	
564	0.064
591	0.088
757	0.115
795	0.127
800	0.131
837	0.138
843	0.122
858	0.140
888	0.149
892	0.164
918	0.156
918	0.194*
996	0.174
1028	0.194
CURVE 5	
323	0.011
773	0.170

T	$\Delta L/L_0$
CURVE 6	
323	0.015
773	0.240
CURVE 7‡	
10	-0.031
15	-0.031
20	-0.031
30	-0.033
40	-0.035
50	-0.037
60	-0.040
70	-0.042
80	-0.043
90	-0.045
100	-0.045
110	-0.046
120	-0.045
130	-0.045

T	$\Delta L/L_0$
CURVE 7 (cont.)‡	
140	-0.044
150	-0.042
160	-0.041
170	-0.039
180	-0.037
190	-0.034
200	-0.032
210	-0.029
220	-0.026
230	-0.023
300	0.003
CURVE 8‡	
303	0.004
323	0.012
363	0.030
403	0.048
443	0.067

T	$\Delta L/L_0$
CURVE 8 (cont.)‡	
483	0.087
523	0.107

DATA TABLE 333. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CADMIUM SULFIDE CdS

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 7‡	
10	-0.12
15	-0.46
20	-0.96
30	-1.92
40	-2.35
50	-2.59
60	-2.29
70	-1.95
80	-1.42
90	-0.90
100	-0.55
110	-0.06
120	0.40
130	0.80
140	1.17

T	α
CURVE 7 (cont.)‡	
150	1.49
160	1.78
170	2.04
180	2.29
190	2.49
200	2.68
210	2.86
220	3.02
230	3.19
300	4.10
CURVE 8‡	
303	4.00
323	4.20

T	α
CURVE 8 (cont.)‡	
363	4.50
403	4.70
443	4.90
483	5.00
523	5.10

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

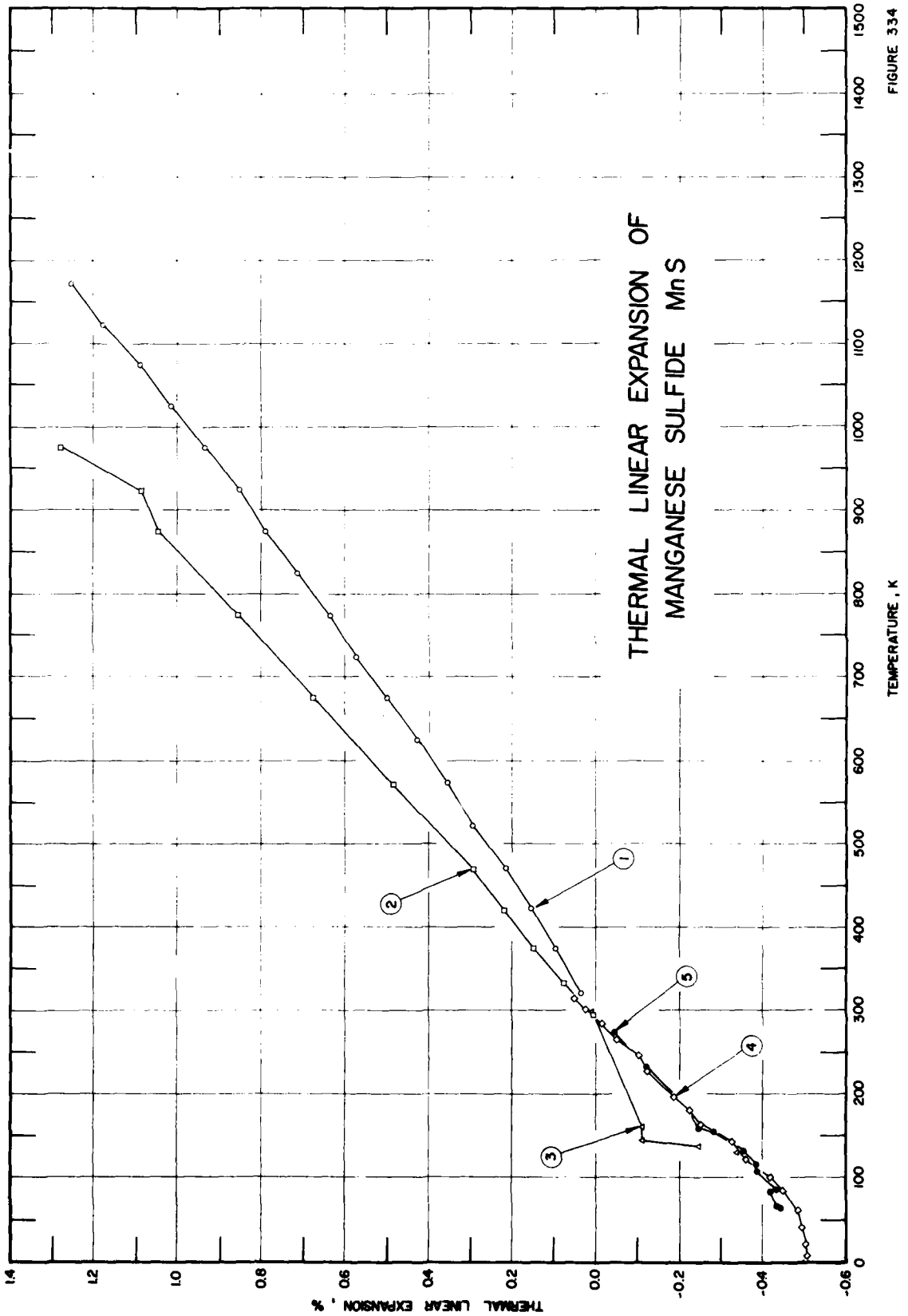

THERMAL LINEAR EXPANSION OF
MANGANESE SULFIDE MnS
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1
2
3
4
5

FIGURE 334

SPECIFICATION TABLE 334. THERMAL LINEAR EXPANSION OF MANGANESE (II) SULFIDE MnS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	909	Moore, J.W. and VanVlack, L.H.	1968	X	321-1171		Specimen -325 mesh powder in silica tube; zero-point correction -0.021% at 293 K.
2	94	Brooksbank, D. and Andrews, K.W.	1968	X	294-975	inclusion in steel	Powder sample; obtained by electrolytic extraction in ferric chloride solution from a free-cutting steel (0.12% C, 1.10% Mn, 0.22% S), after a solution treatment of 1/2 hr at 1100 C, WQ; containing very small traces of silica, spinel and silicates; CrKα radiation used 4-6 hr exposure time; lattice parameter reported at 294 K as 5.2191 Å; 5.2190 Å at 293 K determined by graphical extrapolation.
3	120	Ellefson, B.S. and Taylor, N.W.	1934	X	130-299		The specimen was ground to powder in an agate mortar, supplied by Dr. Maier Charles G. of the Bureau of Mines Pacific Experiment Station, Berkeley, California; lattice parameter reported at 299 K as 5.210 Å; 5.209 Å at 293 K determined by graphical interpolation.
4	130	Morosin, B.	1970	X	7-315		Powder specimen furnished by R. Lindsay; lattice parameter reported at 293 K as 5.2234 Å.
5	980	George, R.	1969		63-300		Lattice parameter reported at 293 K as 5.2224 Å.

DATA TABLE 334. THERMAL LINEAR EXPANSION OF MANGANESE (II) SULFIDE MnS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
321	0.034
374	0.098
422	0.155
471	0.216
522	0.298
574	0.357
624	0.423
675	0.501
724	0.574
773	0.638
824	0.712
873	0.791
925	0.855
973	0.936
1023	1.016
1072	1.096
1122	1.179
1171	1.258

CURVE 2

T	$\Delta L/L_0$
294	0.002
331	0.075
374	0.148
420	0.218
470	0.295
571	0.483
674	0.676
773	0.856
873	1.044
922	1.088
975	1.280

CURVE 3

T	$\Delta L/L_0$
130	-0.340
138	-0.244
143	-0.110
160	-0.110
299	0.004

CURVE 4

T	$\Delta L/L_0$
7.4	-0.509
12.7	-0.501*
17.9	-0.505*
21.7	-0.505
26.9	-0.499*
31.5	-0.499*
36.0	-0.497*
40.9	-0.497
46.2	-0.497*
51.4	-0.492*
55.6	-0.490*
61.1	-0.486
66.8	-0.478*
71.6	-0.472*
77.0	-0.465*
84.2	-0.451
87.7	-0.434*
90.8	-0.432*
1004	-0.421

CURVE 4 (cont.)

T	$\Delta L/L_0$
107.9	-0.390*
113.0	-0.388*
121.5	-0.359
131.7	-0.359*
131.7	-0.342*
134.1	-0.333*
142.8	-0.327
147.1	-0.312*
148.7	-0.315*
151.2	-0.296*
152.9	-0.281*
158.0	-0.262*
163.8	-0.250
180.0	-0.223
196.7	-0.187
217.7	-0.143*
228.6	-0.122
247.0	-0.101
248.2	-0.088*

CURVE 4 (cont.)

T	$\Delta L/L_0$
251.5	-0.076*
253.2	-0.076*
255.9	-0.068*
265.5	-0.053
274.9	-0.040*
284.7	-0.015
293.0	0.000*
295.8	0.000*
301.1	0.021
305.5	0.026*
315.7	0.049

CURVE 5

T	$\Delta L/L_0$
63	-0.442
66	-0.437
84	-0.421
87	-0.435
108	-0.389

CURVE 5 (cont.)

T	$\Delta L/L_0$
114	-0.385
132	-0.354
154	-0.281
159	-0.243
178	-0.228*
232	-0.119
274	-0.046
293	0.000*
300	0.021*

* Not shown in figure.

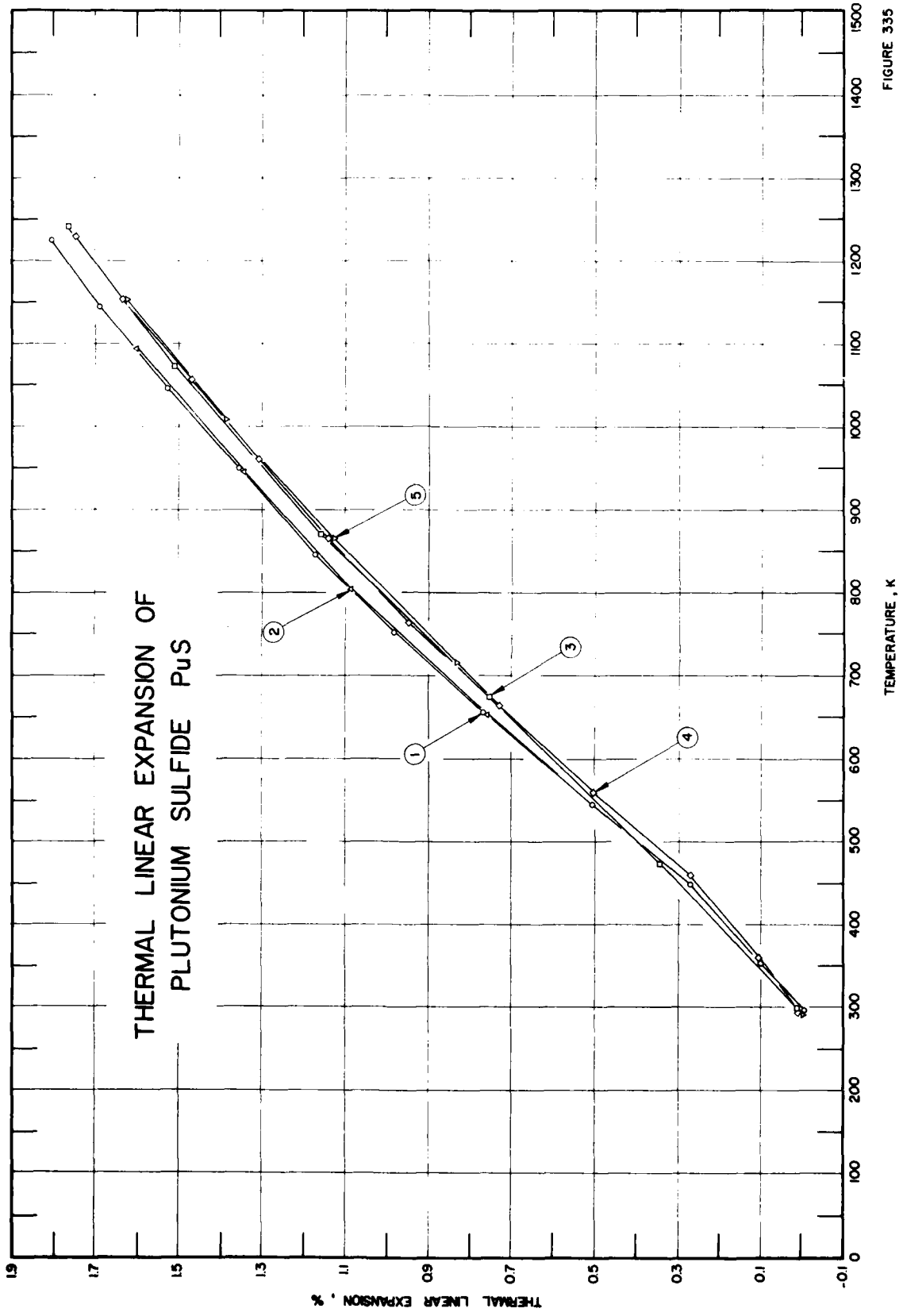

THERMAL LINEAR EXPANSION OF
PLUTONIUM SULFIDE PuS
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1
2
3
4
5
-0.1
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 335

SPECIFICATION TABLE 335. THERMAL LINEAR EXPANSION OF PLUTONIUM SULFIDE PuS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	866	Kruger, O. L. and Moser, J. B.	1966	L	297-1227		Starting material 99.97 pure plutonium with 0.013 impurities; PuS prepared by high temperature homogenization of the product from the reaction of H_2S gas with partly decomposed plutonium hydride prepared by reaction of plutonium with flowing high purity hydrogen at 473 K; specimen 0.7 cm diameter and 1.3 cm long pellet, formed at 21.1 kg/mm^2 and heated at 373 K for 2 hr; all operation carried out in an inert atmosphere of high-purity nitrogen gas; measured with increasing temperature; zero-point correction -0.076% at 293 K.
2	866	Kruger, O. L. and Moser, J. B.	1966	L	1094-653		The above specimen; except measured with decreasing temperature.
3	137	Kruger, O. L. and Moser, J. B.	1965	L	300-1242		Zero-point correction is 0.013% at 293 K.
4	912	Kruger, O. L. and Moser, J. B.	1964		295-1231		Expansion measured with increasing temperature; zero-point correction -0.003% at 293 K.
5	912	Kruger, O. L. and Moser, J. B.	1964		1155-292		Expansion measured with decreasing temperature; zero-point correction -0.003% at 293 K.

DATA TABLE 335. THERMAL LINEAR EXPANSION OF PLUTONIUM SULFIDE PuS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
297	-0.005
352	0.100
449	0.271
547	0.505
657	0.770
752	0.983
847	1.174
950	1.357
1047	1.526
1145	1.689
1227	1.808

CURVE 2

T	$\Delta L/L_0$
1094	1.606
945	1.344
804	1.088
653	0.760

CURVE 3

T	$\Delta L/L_0$
300	0.013
475	0.344
674	0.756
871	1.160
1073	1.513
1242	1.766

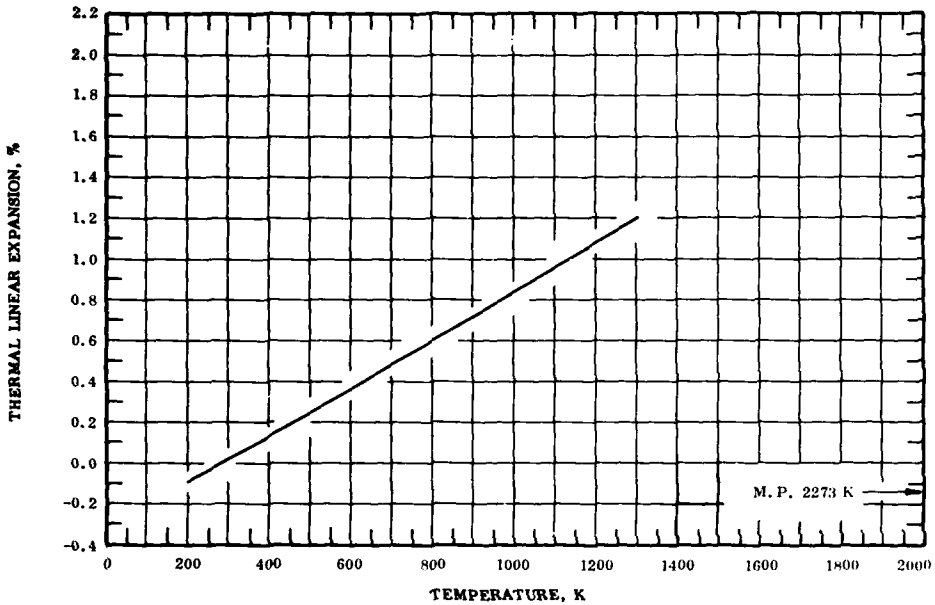
CURVE 4

T	$\Delta L/L_0$
295	0.008
361	0.103
459	0.273
561	0.503
664	0.731
764	0.951
867	1.141
961	1.309
1058	1.468
1154	1.635
1231	1.751

CURVE 5

T	$\Delta L/L_0$
1155	1.624
1009	1.385
867	1.127
717	0.836
292	-0.001

FIGURE AND TABLE NO. 336R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF URANIUM SULFIDE US



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
200	-0.100	10.6
250	-0.043	10.9
293	0.000	11.1
300	0.008	11.1
400	0.122	11.5
500	0.238	11.8
600	0.357	12.0
700	0.478	12.3
800	0.602	12.5
900	0.728	12.7
1000	0.857	12.9
1100	0.987	13.1
1200	1.119	13.3
1300	1.254	13.5

REMARKS

The recommended values are considered accurate to within ± 5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.315 + 1.033 \times 10^{-3}\ T + 1.541 \times 10^{-7}\ T^2 - 1.601 \times 10^{-11}\ T^3$$

The tabulated values for the coefficient of thermal expansion are derived by differentiating the above equation and are considered accurate to about ± 10%.

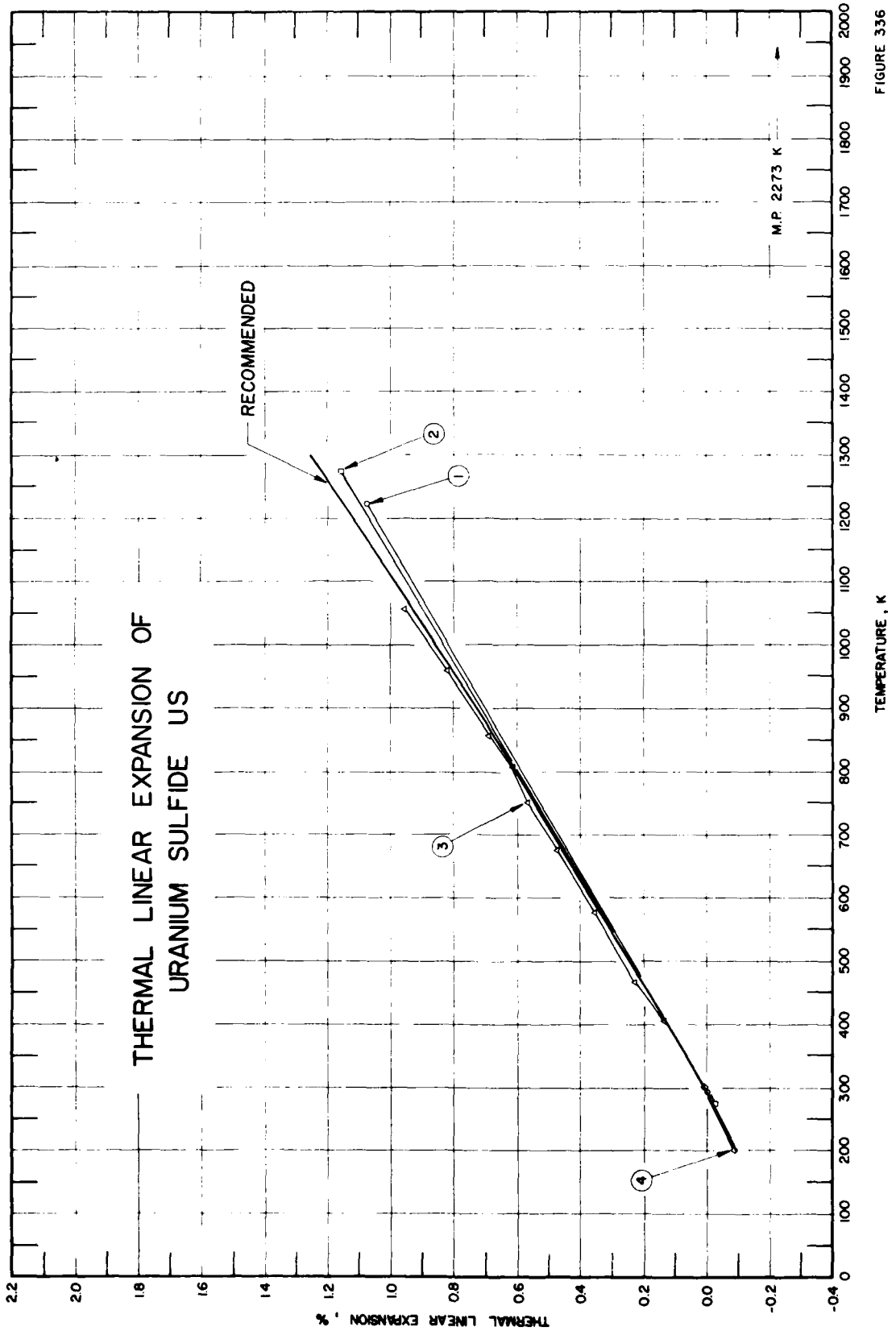

THERMAL LINEAR EXPANSION OF URANIUM SULFIDE US
RECOMMENDED
M.P. 2273 K
1
2
3
4
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 336

SPECIFICATION TABLE 336. THERMAL LINEAR EXPANSION OF URANIUM SULFIDE US

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	915	Shalek, P.D.	1963		293,1223		0.01 to 0.06 metallic impurities; specimen prepared from highly reactive uranium; produced by hydriding metal turnings at 523 K, decomposed at 823 K, reacted with stoichiometric amount of H_2S (about 99.5 H_2S) at 673 K to 823 K, ground to -100 mesh, blended, loosely packed in tungsten crucible in argon atm, homogenized in vacuum (2×10^{-4} to 1×10^{-5} mm Hg) or in inert atm at 1973 K to 2073 K, ground to -100 mesh in argon atm, preformed at 415 kg/cm^2 in argon atm, isostatically pressed at 1523 kg/cm^2 with binder of 1 wt.% carbowax and water, and sintered in vacuum or in inert atm at 1973 K to 2323 K; melting point 2723 K; measured in vacuum.
2	914	Shalek, P.D.	1962		273,1273		Specimen prepared from uranium powder obtained from the hydride, reacted with stoichiometric H_2S at 773 to 973 K, homogenized to monosulfide phase at around 2073 K, pressed into pellets at 1523 kg/cm^2 and sintered at 2073 to 2373 K.
3	713	Street, R.S. and Rand, M.H.	1963	X	293-1056		Specimen prepared by heating sulfur and uranium powders in evacuated silica ampoule for 2 days at 673 K, then 1 day at 1073 K; homogenized by heating in vacuum 30 min at 2073 K; no UOS apparent in x-ray analysis; only face-centered cubic phase found; lattice parameter reported at 293 K as 5.4869 Å.
4	843	Lander, G.H. and Mueller, M.H.	1974	X	200-300		Particle size ~40 μm crystal structure like NaCl, powder, die pressed at 527 kg/cm^2 into flat disk; placed in milled recess in copper sample holder, disk covered with 0.0005 cm thick Mylar window, sealed with copper frame and resin; lattice parameter reported at 300 K as 5.489 Å.

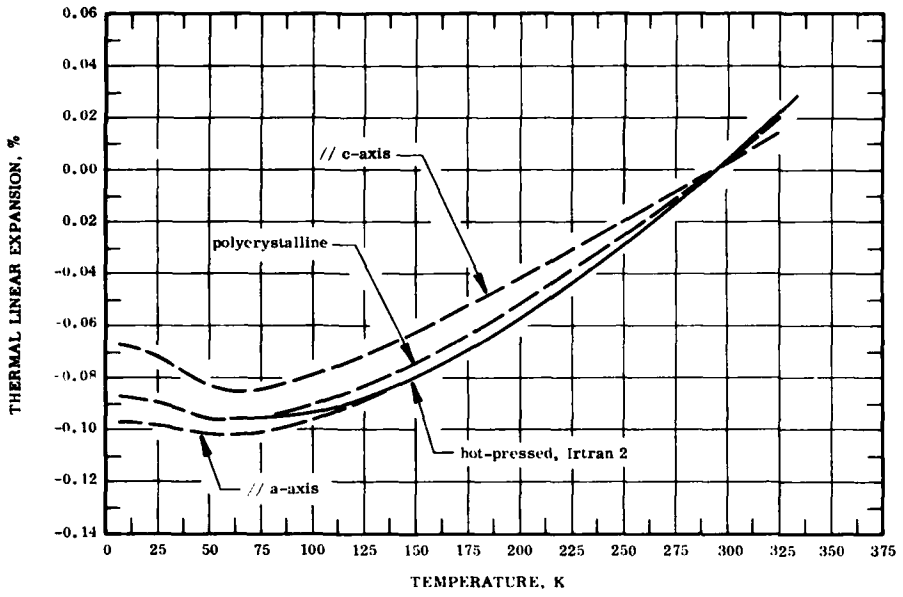
DATA TABLE 336. THERMAL LINEAR EXPANSION OF URANIUM SULFIDE US

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000*
1223	1.079
CURVE 2	
273	-0.024*
1273	1.156
CURVE 3	
293	0.000*
403	0.136*
468	0.224
576	0.355
673	0.473
750	0.563
808	0.616
856	0.687
959	0.820
1056	0.956
CURVE 4	
200	-0.091
293	0.000*
300	0.006*

* Not shown in figure.

FIGURE AND TABLE NO. 337R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF ZINC SULFIDE ZnS



RECOMMENDED VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

	// a-axis	// c-axis	polycrystalline		Hot-Pressed (Irtran 2)	
T	$\Delta L/L_0$ †	$\Delta L/L_0$ †	$\Delta L/L_0$ †	α	$\Delta L/L_0$	α
5	-0.097	-0.067	-0.087			
25	-0.098	-0.071	-0.089			
50	-0.101	-0.083	-0.095			
60	-0.102	-0.085	-0.096	1.2	-0.096	0.4
80	-0.100	-0.083	-0.094	1.9	-0.096	0.8
100	-0.096	-0.079	-0.090	2.5	-0.093	1.7
120	-0.090	-0.073	-0.084	3.1	-0.089	2.6
140	-0.083	-0.066	-0.078	3.5	-0.083	3.4
160	-0.075	-0.059	-0.070	3.9	-0.075	4.1
180	-0.066	-0.051	-0.061	4.2	-0.067	4.7
200	-0.057	-0.042	-0.052	4.4	-0.057	5.2
220	-0.046	-0.033	-0.042	4.6	-0.046	5.6
240	-0.034	-0.024	-0.031	4.7	-0.034	6.0
260	-0.022	-0.015	-0.020	4.8	-0.022	6.3
280	-0.009	-0.006	-0.008	4.9	-0.009	6.6
293	0.000	0.000	0.000	5.0	0.000	6.8
300	0.005	0.004	0.005	5.0	0.005	6.9
315	0.015	0.010	0.013	5.1	0.015	7.0
325	0.022	0.014	0.019	5.1	0.022	7.1
335					0.028	7.1

† Provisional values.

REMARKS

The recommended values for hot-pressed sample commonly known as Irtran 2 are based on curves 5 to 7. These are considered accurate to within ± 5%. The provisional values for powdered polycrystalline sample are calculated from the selected axial thermal linear expansion data (curves 1 and 2). These are considered accurate to within ± 10%. The tabulated values for the thermal linear expansion are represented approximately by the following equations:

// a-axis: $\Delta L/L_0 = -0.103 - 1.153 \times 10^{-4}\ T + 2.020 \times 10^{-6}\ T^2 - 1.482 \times 10^{-9}\ T^3$ (60-325 K)

// c-axis: $\Delta L/L_0 = -8.617 \times 10^{-2} - 1.291 \times 10^{-4}\ T + 2.387 \times 10^{-6}\ T^2 - 3.202 \times 10^{-9}\ T^3$ (60-325 K)

polycrystalline: $\Delta L/L_0 = -9.705 \times 10^{-2} - 1.212 \times 10^{-4}\ T + 2.149 \times 10^{-6}\ T^2 - 2.068 \times 10^{-9}\ T^3$ (60-325 K)

Hot-Pressed (Irtran 2): $\Delta L/L_0 = -8.638 \times 10^{-2} - 3.386 \times 10^{-4}\ T + 3.018 \times 10^{-6}\ T^2 - 2.921 \times 10^{-9}\ T^3$ (60-335 K)

The tabulated values for the coefficient of thermal expansion for hot-pressed sample are based on the selected experimental data and those for the powdered polycrystalline sample are calculated by differentiating the above equation. These values are considered accurate to about ± 10% and ± 15% respectively.

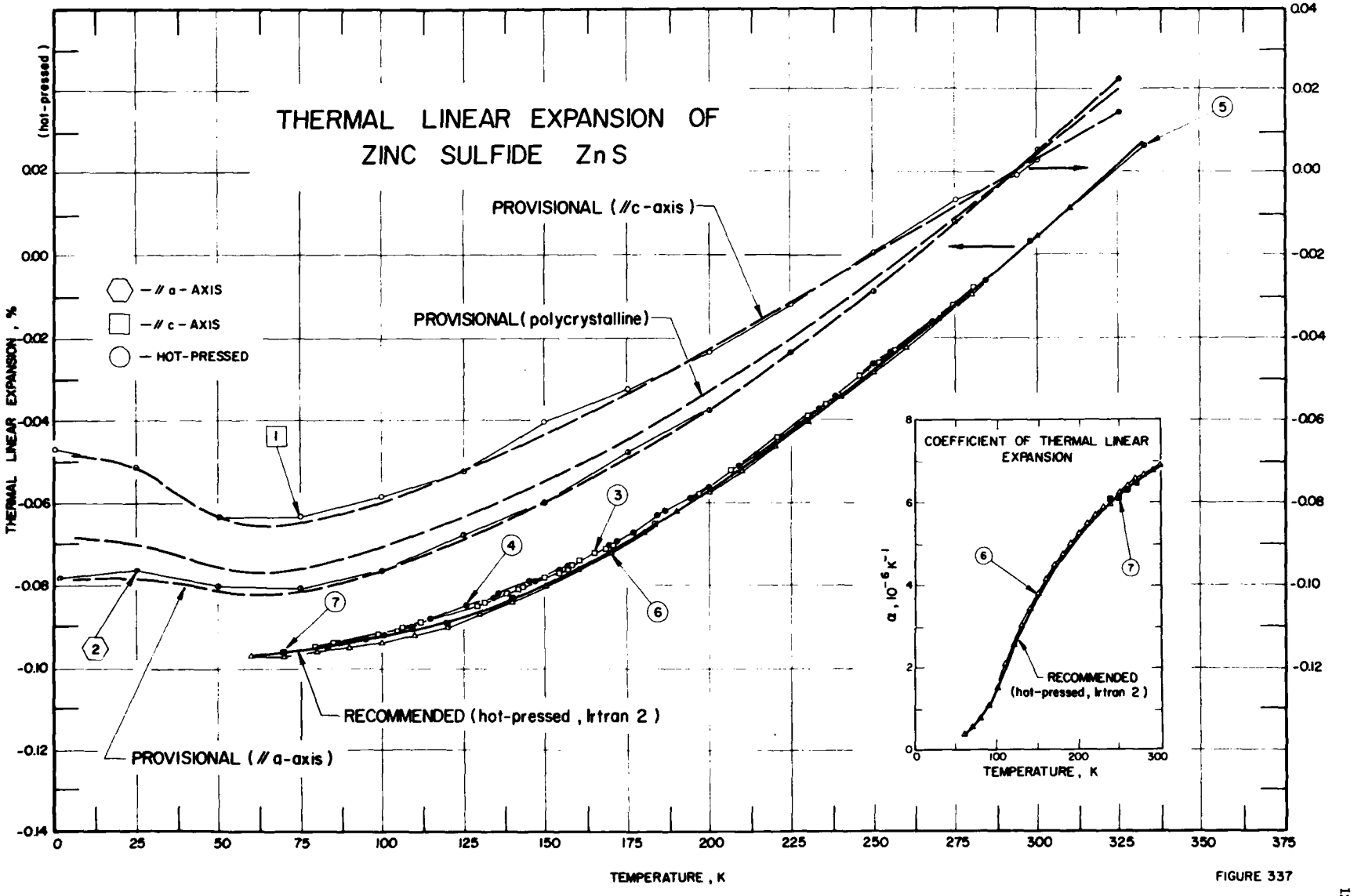

THERMAL LINEAR EXPANSION OF
ZINC SULFIDE ZnS
PROVISIONAL (// c-axis)
PROVISIONAL (polycrystalline)
— // a - AXIS
— // c - AXIS
— HOT-PRESSED
RECOMMENDED (hot-pressed, Irtran 2)
PROVISIONAL (// a-axis)
THERMAL LINEAR EXPANSION, % (hot-pressed)
TEMPERATURE, K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α, 10⁻⁶ K⁻¹
RECOMMENDED (hot-pressed, Irtran 2)
TEMPERATURE, K

FIGURE 337

SPECIFICATION TABLE 337. THERMAL LINEAR EXPANSION OF ZINC SULFIDE ZnS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	916, 918	Reeber, R.R. and Powell, G.W.	1967	X	2-317		Eagle-Pieher ultrapure-grade, synthesized between 1323 and 1398 K; as-received ZnS sealed in quartz capsule, in vacuum, heated at 1482 K for 1 hr and water quenched; material sieved through a 325-mesh screen without mortaring; cobalt K_α radiation used, filtered with iron foil; specimen directly contact with helium, nitrogen or Freon-12 bath; 310, 116, 222, 222_2, 311, 311_2, and 304 lines used to calculate the lattice parameters; measured along c_0-direction; lattice parameter reported at 293 K as 6.2604 Å; smooth data reported.
2	916, 918	Reeber, R.R. and Powell, G.W.	1967	X	2-317		The above specimen; measured along a_0-direction; smooth data reported; lattice parameter reported at 293 K as 3.8225 Å.
3	917	Kobyakov, I.B. and Smolenko, L.A.	1967	L	79-281		Hexagonal; sample of near-cube shape with dimensions 9.60 x 9.54 x 9.98 mm; deviation from parallelism not exceed 5 μ and 15′ error in the orientation of the faces; data from 7 series of measurements along OZ-axis.
4	917	Kobyakov, I.B. and Smolenko, L.A.	1967	L	79-295		The above specimen; data from 5 series of measurements along OX-axis.
5	358	Ballard, S.S. and Browder, J.S.	1966	I	298-333	Irtran 2	Infrared-transmitting optical material, microcrystalline, hot-pressed compact developed by the Eastman Kodak Co. of New York; low emissivity; high refractive index for lenses, translucent yellow; at 25 C transmittance 0.7 to 14.5 μ, density 4.09 g/cc; reported error <2.0%.
6	749	Browder, J.S. and Ballard, S.S.	1969	L/E	65-310	Irtran 2	Microcrystalline, hot-pressed compact developed by the Eastman Kodak Co. of Rochester, New York.
7	327	Browder, J.S.	1967	L	60-310	Irtran 2	Dimensions: right cylinder specimen, 0.63 cm diameter x 1.27 cm long, opposite ends polished parallel to within 20 μm; polycrystalline material, artificially produced infrared-transmitting optical, developed by Eastman Kodak Co.; reported error ±5%.

DATA TABLE 337. THERMAL LINEAR EXPANSION OF ZINC SULFIDE ZnS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
0	-0.067
25	-0.071
50	-0.083
75	-0.083
100	-0.078
125	-0.072
150	-0.060
175	-0.052
200	-0.043
225	-0.031
250	-0.019
275	-0.006
293	0.000
300	0.004
325	0.016
CURVE 2	
0	-0.097
25	-0.096
50	-0.100
75	-0.101
100	-0.096
125	-0.087
150	-0.079
175	-0.067
200	-0.057
225	-0.043
250	-0.028
275	-0.011
293	0.000
300	0.006
325	0.023
CURVE 3‡	
79	-0.095
81	-0.095*
85	-0.094
85	-0.094
97	-0.092
98	-0.092
98	-0.092
100	-0.092
105	-0.091
107	-0.090
112	-0.089
123	-0.086*
123	-0.086*
129	-0.085
132	-0.084*
132	-0.084
138	-0.082
142	-0.081
143	-0.080
150	-0.078
154	-0.077*
154	-0.077
157	-0.076
158	-0.075
161	-0.074
165	-0.072*
165	-0.072
166	-0.072*
168	-0.071
171	-0.070
178	-0.067*
179	-0.067*
183	-0.065
195	-0.059*
197	-0.058
206	-0.053*
207	-0.052
219	-0.046*
221	-0.044
229	-0.040*
230	-0.039
231	-0.039*
236	-0.036
246	-0.029
248	-0.028*
252	-0.026
257	-0.023
269	-0.015*
274	-0.012
280	-0.008*
281	-0.008
CURVE 4‡	
79	-0.095*
81	-0.095*
83	-0.095
86	-0.095*
87	-0.094
95	-0.093*
95	-0.093
97	-0.092*
98	-0.092*
101	-0.092
104	-0.091*
106	-0.091*
109	-0.090
115	-0.088
116	-0.088*
117	-0.088*
126	-0.085
126	-0.085*
134	-0.083*
134	-0.083
136	-0.082
145	-0.079
147	-0.079*
147	-0.079
154	-0.076
157	-0.075
160	-0.074*
166	-0.071*
167	-0.071*
169	-0.070
172	-0.069*
172	-0.069
177	-0.067
178	-0.066*
184	-0.063
187	-0.062*
187	-0.062*
187	-0.062
194	-0.059*
194	-0.059
198	-0.057*
199	-0.056*
200	-0.056
206	-0.053*
206	-0.053*
207	-0.052*
209	-0.051
215	-0.048
220	-0.045*
220	-0.045*
227	-0.041
231	-0.039*
233	-0.037
238	-0.034
242	-0.032*
244	-0.031*
251	-0.026
256	-0.023
260	-0.021*
268	-0.016*
268	-0.016
279	-0.009*
284	-0.006
291	-0.001*
295	0.001*
CURVE 5	
298	0.004
333	0.027
CURVE 6‡	
60	-0.097
70	-0.097
80	-0.096
90	-0.095
100	-0.094
110	-0.092
120	-0.090
130	-0.087
140	-0.084
150	-0.080
160	-0.076
170	-0.072
180	-0.067
190	-0.062
200	-0.057
210	-0.052
220	-0.046
230	-0.040
240	-0.034
250	-0.028
260	-0.022
270	-0.015
280	-0.009
290	-0.002
300	0.005
310	0.012
CURVE 7‡	
60	-0.097*
70	-0.096
80	-0.096*
90	-0.095*
100	-0.094*
110	-0.092*
120	-0.089
130	-0.087*
140	-0.083
150	-0.080*
160	-0.076*
170	-0.072*
180	-0.067*
190	-0.062*
200	-0.057*
210	-0.052*
220	-0.046*
230	-0.040*
240	-0.034*
250	-0.028*
260	-0.022*
270	-0.015*
280	-0.009*
290	-0.002*
300	0.005*
310	0.012*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 337. COEFFICIENT OF THERMAL LINEAR EXPANSION OF ZINC SULFIDE ZnS

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3‡	
79	1.02
81	0.75
85	0.79
85	1.84
97	1.65
98	1.83
98	1.62
100	1.74
105	2.16
107	2.00
112	2.22
123	2.95
123	2.64
129	2.90
132	3.06
132	2.82
138	3.32
142	3.15
143	3.07
150	3.24
154	3.54
154	4.00
157	4.06
158	3.91
161	3.93
165	3.96
165	4.24
166	4.12
168	4.25
171	4.09
178	4.28
179	4.40
183	5.01
195	5.00
197	5.07
206	5.47
207	5.16
219	6.00
221	6.00
229	5.53
230	5.42
231	6.09
236	6.35
246	6.05
248	6.27
252	6.29

T	α
CURVE 3 (cont.)‡	
257	6.22
269	6.28
274	6.04
280	6.34
281	6.39
CURVE 4‡	
79	1.51
81	0.82
83	1.59
86	1.41
87	1.71
95	1.94
95	2.25
97	2.04
98	1.87
101	1.98
104	2.07
106	2.43
109	2.11
115	3.05
116	2.78
117	3.29
126	2.58
126	2.86
134	3.17
134	3.67
136	3.05
145	3.38
147	3.66
147	4.12
154	3.35
157	3.82
160	3.85
166	4.40
167	4.22
169	3.96
172	4.00
172	4.13
177	4.20
178	4.48
184	4.73
187	4.67
187	4.78
187	4.48

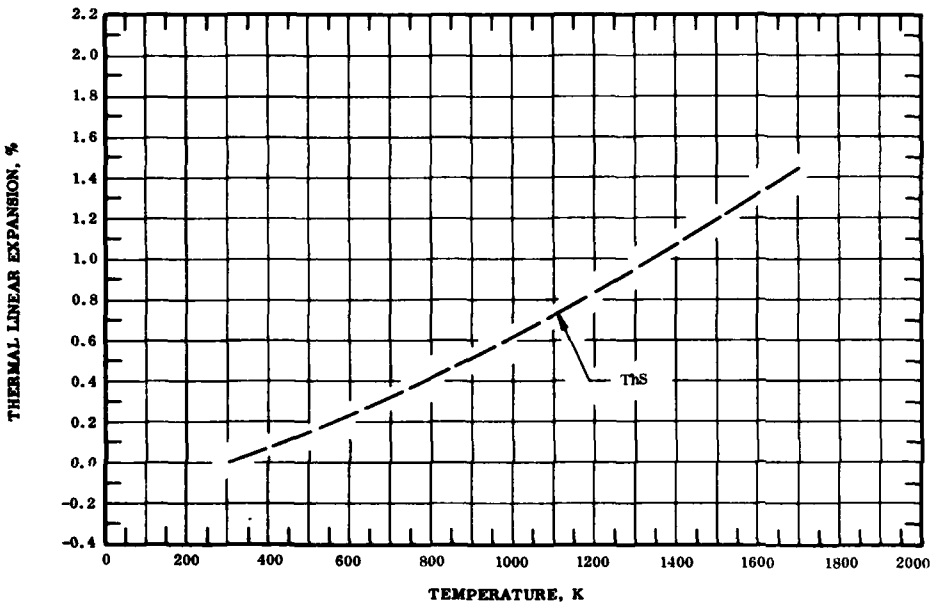
T	α
CURVE 4 (cont.)‡	
194	4.86
194	4.72
198	4.96
199	4.84
200	5.13
206	4.98
206	5.29
207	5.42
209	5.18
215	5.86
220	5.95
220	5.76
227	5.87
231	5.81
233	5.87
238	6.25
242	6.06
244	6.17
251	6.42
256	5.99
260	6.09
268	6.69
268	6.15
279	6.27
284	6.26
291	6.39
295	6.25
CURVE 6‡	
60	0.34
70	0.53
80	0.75
90	1.07
100	1.52
110	2.08
120	2.57
130	3.01
140	3.40
150	3.78
160	4.14
170	4.48
180	4.76
190	5.03
200	5.26
210	5.50

T	α
CURVE 6 (cont.)‡	
220	5.70
230	5.90
240	6.00
250	6.20
260	6.40
270	6.60
280	6.70
290	6.80
300	6.90*
310	7.00*
CURVE 7‡	
60	0.34*
70	0.53*
80	0.75*
90	1.07*
100	1.52*
110	2.08*
120	2.57*
130	3.01*
140	3.40*
150	3.78*
160	4.14*
170	4.48*
180	4.76*
190	5.03*
200	5.26*
210	5.47*
220	5.67*
230	5.86*
240	6.02
250	6.18
260	6.35
270	6.51
280	6.65*
290	6.79*
300	6.91*
310	7.02*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 338R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF MISCELLANEOUS SULFIDES



PROVISIONAL VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

	ThS	
T	$\Delta L/L_0$	α
293	0.000	7.0
300	0.004	7.1
400	0.077	7.6
500	0.156	8.1
600	0.239	8.6
700	0.328	9.1
800	0.421	9.6
900	0.519	10.0
1000	0.621	10.5
1100	0.728	10.9
1200	0.828	11.3
1300	0.953	11.6
1400	1.071	12.0
1500	1.192	12.3
1600	1.317	12.6
1700	1.445	12.9

REMARKS

ThS - The provisional values are based on the most recent measurement (curve 26) and are considered accurate to within ± 7%. These values are represented by the following equation:

$$\Delta L/L_0 = -0.180 + 5.242 \times 10^{-4}\ T + 3.101 \times 10^{-7}\ T^2 - 3.316 \times 10^{-11}\ T^3$$

The tabulated values for the coefficient of thermal expansion are primarily derived by differentiating the above equation and are considered accurate to about ± 10%.

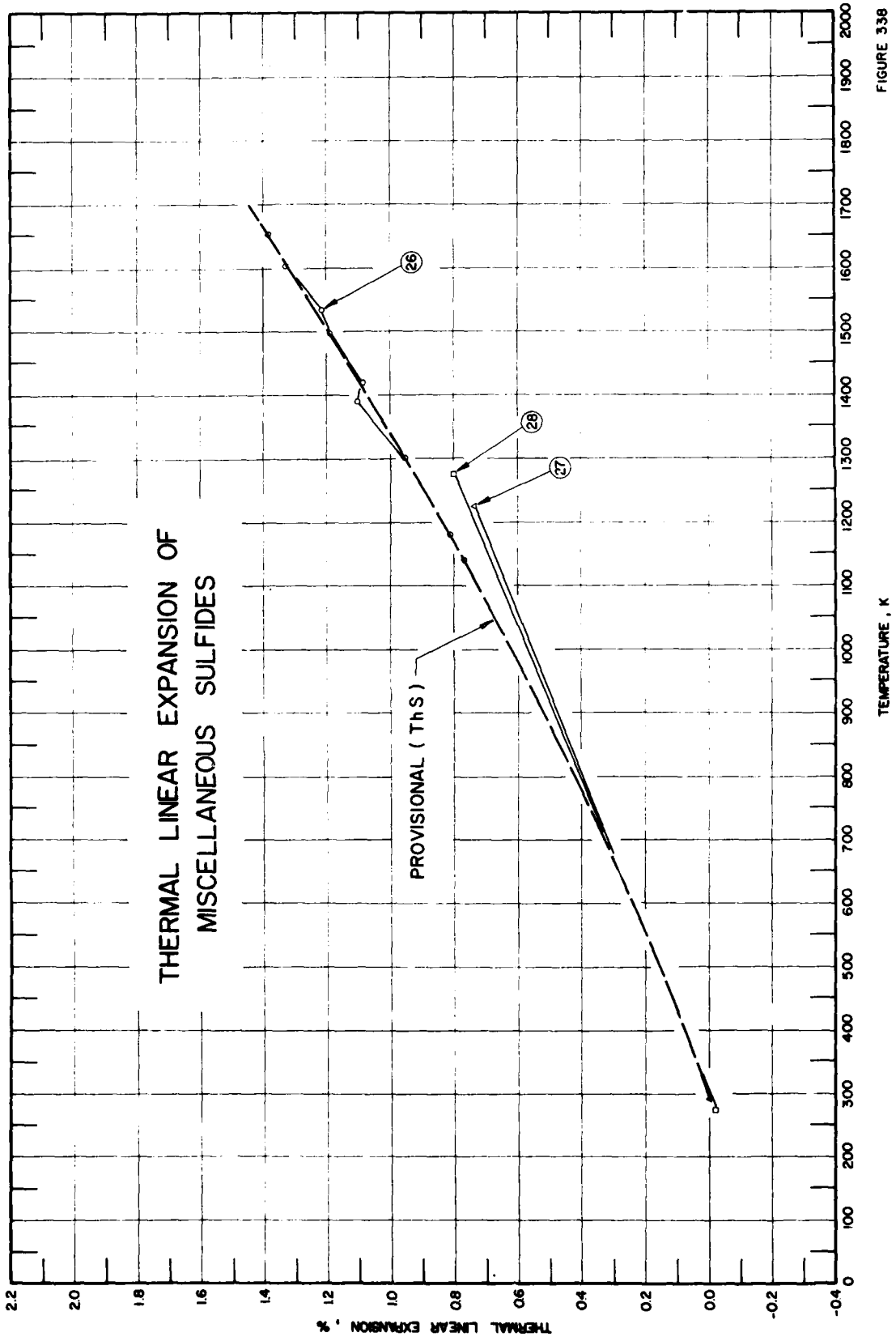

THERMAL LINEAR EXPANSION OF
MISCELLANEOUS SULFIDES
PROVISIONAL (ThS)
26
28
27
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 338

SPECIFICATION TABLE 338. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SULFIDES

Cur. No	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	632	Bridgman, P.W.	1932		303,348	BaS	Barium sulfide; dimensions: cylindrical, 0.94 cm diameter x 0.94-1.27 cm long; specimen was pressed; expansion measured by lever piezometer.
2*	632	Bridgman, P.W.	1932		303,348	CaS	Calcium sulfide; dimensions: cylindrical, 0.91 cm diameter x 0.91-1.27 cm long; specimen was pressed; expansion measured by lever piezometer.
3*	919	Baenziger, N.C. and Duax, W.L.	1968	X	98-158	CS_2	Carbon disulfide; single crystal specimen grown from reagent grade liquid CS_2; expansion measured along a-axis; lattice parameter reported at 98 K as 6.215 Å; this curve is here reported using 98 K as reference temperature at which $\Delta L/L_0 = 0$.
4*	919	Baenziger, N.C. and Duax, W.L.	1968	X	98-158	CS_2	Carbon disulfide; the above specimen; expansion measured along b-axis; lattice parameter reported at 98 K as 5.404 Å; this curve is here reported using 98 K as reference temperature at which $\Delta L/L_0 = 0$.
5*	919	Baenziger, N.C. and Duax, W.L.	1968	X	98-158	CS_2	Carbon disulfide; the above specimen; expansion measured along c-axis; lattice parameter reported at 98 K as 5.404 Å; this curve is here reported using 98 K as reference temperature at which $\Delta L/L_0 = 0$.
6*	907	Marchenko, V.I. and Samsonov, G.V.	1963		293,1293	CeS	Cerium monosulfide; almost stoichiometric CeS; polycrystalline; sintered; melting point 2723 K; measured in argon atm; data are mean of three measurements.
7*	907	Marchenko, V.I. and Samsonov, G.V.	1963		293,1293	Ce_2S_3	Cerium(III) sulfide; almost stoichiometric Ce_2S_3; polycrystalline; sintered; melting point 2163 K; measured in argon atm; data are mean of three measurements.
8*	908	Goryachev, Yu.M. and Kutsenok, T.G.	1968	L	293,1273	$CeS_{1.4}$	Cerium(III) sulfide; dimensions: cylindrical, 3 mm diameter x 12-15 mm long; made by powder-metallurgy technique; expansion measured in an inert atm; reported error about 1.5%.
9*	908	Goryachev, Yu.M. and Kutsenok, T.G.	1968	L	298,1273	$CeS_{1.36}$	Cerium sulfide; similar to the above specimen except different composition.
10*	908	Goryachev, Yu.M. and Kutsenok, T.G.	1968	L	298,1273	$CeS_{1.32}$	Cerium sulfide; similar to the above specimen except different composition.
11*	870	Lashkarev, G.V., Dudnik, E.M., and Paderno, Yu.B.	1966	L	300,800	EuS	Europium sulfide; prepared from 99.95+ pure materials.
12*	907	Marchenko, V.I. and Samsonov, G.V.	1963		293,1293	LaS	Lanthanum monosulfide; almost stoichiometric LaS; polycrystalline; sintered; melting point 2243 K; measured in argon atm; data are mean of three measurements.
13*	907	Marchenko, V.I. and Samsonov, G.V.	1963		298,1293	La_2S_3	Lanthanum sulfide; almost stoichiometric La_2S_3; polycrystalline; sintered; melting point 2423 K; measured in argon atm; data are mean of three measurements.
14*	910	Young, P.A.	1968	X	78-374	MoS_2	Molybdenum disulfide; 99.96 pure, crystal cleaved from single parent crystal; expansion measured along a-axis; lattice parameter reported at 293 K as 3.1472 Å.
15*	907	Marchenko, V.I. and Samsonov, G.V.	1963		293,1293	NdS	Neodymium monosulfide; sulfur content < 1% below stoichiometric; polycrystalline; sintered; measured in argon atm; data are mean of three measurements.

* Not shown in figure.

SPECIFICATION TABLE 338. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SULFIDES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
16*	907	Marchenko, V.I. and Samsonov, G.V.	1963		293, 1293	Nd_2S_3	Neodymium sulfide; sulfur content <1% below stoichiometric; polycrystalline; sintered; melting point 2283 K; measured in argon atm; data are mean of three measurements.
17*	911	Clever, H.L., Westrum, E.F., Jr., and Cordes, A.W.	1965	X	295, 308	P_4S_3	Phosphorus sesquisulfide; sample supplied by Dr. A. W. Cordes, Eastman technical grade material, purified by being subjected to boiling water, to repeated extraction with carbon disulfide; powdered trisulfide sample; crystal II, low temperature form, orthorhombic (D_{2h}-P_{nmb}) with eight molecules in the unit cell.
18*	911	Clever, H.L., et al.	1965	X	319, 337	P_4S_3	Phosphorus sesquisulfide; similar to the above specimen; crystal I, high temperature form, presumably plastic; molecular structure not known.
19*	907	Marchenko, V.I. and Samsonov, G.V.	1963		293, 1293	PrS	Praseodymium monosulfide; sulfur content <1% below stoichiometric; polycrystalline; sintered; measured in argon atm; data are mean of three measurements.
20*	907	Marchenko, V.I. and Samsonov, G.V.	1963		293, 1293	Pr_2S_3	Praseodymium sulfide; sulfur content <1% below stoichiometric; polycrystalline; sintered; melting point 2068 K; measured in argon atm; data are mean of three measurements.
21*	870	Lashkarev, G.V., Dudnik, E.M., and Paderno, Yu.B.	1966	L	300, 800	Sm_2S_3	Samarium(III) sulfide; starting materials 99.95+ pure Sm and S; prismatic specimen prepared by heating powders.
22*	913	Faktor, M.M., Hanks, R., and Lemon, T.H.	1968	L	297-735	Ag_3AsS_3	Silver thioarsenate; 0.0635 impurity (0.025 Sb, 0.020 Se, 0.010 Fe, 0.0025 Au, 0.0015 Cu, 0.0025 Pb, 0.0020 Si); single-crystal, provided by Dr. S. E. R. Hiscocks of the Royal Radar Establishment, Malvern; melting point 753 K; specimen placed in sealed evacuated (10^{-3} torr), thin-walled silica capsule, cycled twice between room temperature and 723 K at rate of 2 K min^{-1}, then heated to m.p., fused and re-solidified; expansion measured along a-axis; zero-point correction 0.006% at 293 K.
23*	913	Faktor, M.M., et al.	1968	L	297-718	Ag_3AsS_3	Silver thioarsenate; the above specimen; expansion measured along b-axis; zero-point correction 0.004% at 293 K.
24*	913	Faktor, M.M., et al.	1968	L	297-737	Ag_3AsS_3	Silver thioarsenate; the above specimen; expansion measured along c-axis; zero-point correction 0.008% at 293 K.
25*	773	Khan, A.A. and Deshpande, V.T.	1968	X	303-546	SrS	Strontium monosulfide; lattice parameter reported at 203 K as 6.0233 Å; 6.0226 Å at 293 K determined by graphical extrapolation.
26	172	Aronson, S., Cisney, E., and Gingerich, K.A.	1967	X	1141-1652	ThS	Thorium sulfide; thorium metal powder reacted with H_2S at 873 K to form ThS_2; ThS_2 mixed with thorium powder, pressed into pellet, and heated at 1923 K for 1 hr to form ThS; melting point 2608 K.
27	907	Marchenko, V.I. and Samsonov, G.V.	1963		293, 1223	ThS	Thorium sulfide; specimen prepared from highly reactive thorium; 0.09 metallic impurities; produced by hydriding metal turnings at 473 to 773 K, decomposed at 1023 K, reacted with stoichiometric amount of H_2S (about 99.5 H_2S) at 973 K, ground to -100 mesh, blended, loosely packed in tungsten crucible in argon atm, homogenized in vacuum (2×10^{-4} to 1×10^{-5} mm Hg) or in inert atm at 2073 to 2173 K, ground to -100 mesh in argon atm, preformed at 1055 kg cm^{-2} in argon atm, isostatically pressed at 3870 kg cm^{-2} with binder of 1 wt.% carbowax and water, and sintered in vacuum or in inert atm at 2173 K to 2373 K; melting point 2608 K; measured in vacuum.

* Not shown in figure.

SPECIFICATION TABLE 338. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SULFIDES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
28	914	Shalek, P.D.	1962		273, 1273	ThS	Thorium sulfide; specimen prepared from thorium powder obtained from the hydride, reacted with stoichiometric H_2S at 773 K to 973 K, homogenized to monosulfide phase at around 2073 K, pressed into pellets at 3870 kg cm^{-2}, and sintered at 2073 K to 2373 K.
29*	920	Plumat, E.R.	1968		293-612	GeS + $\Sigma X_1 S$	80.0 GeS_2, 15.0 CdS, 5.0 Na_2S; constituents weighed in dry atmosphere, mixed, melted and fired at 1173 K in atmosphere of N_2 + 5% H_2; specimen poured molten into molds as rods and plates.
30*	920	Plumat, E.R.	1968		286-761	GeS + $\Sigma X_1 S$	90.0 GeS_2, 10.0 Li_2S; constituents weighed in dry atmosphere, mixed, melted and fired at 1173 K in atmosphere of N_2 + 5% H_2; specimens poured molten into molds as rods and plates; zero-point correction -0.008% at 293 K.

* Not shown in figure.

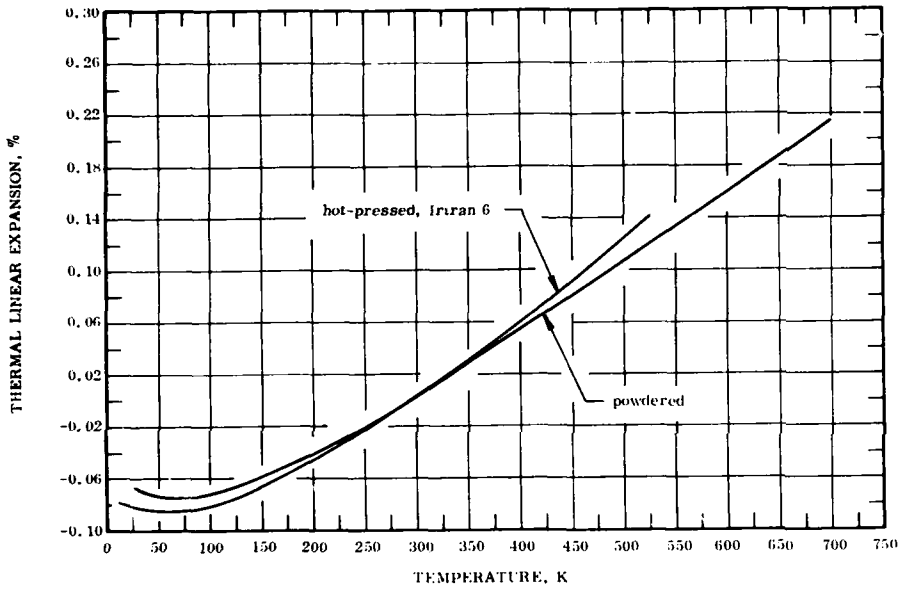
DATA TABLE 338. THERMAL LINEAR EXPANSION OF MISCELLANEOUS SULFIDES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
303	0.034
348	0.187
CURVE 2*	
303	0.017
348	0.094
CURVE 3*	
98	0.000
105	0.270
138	1.560
143	2.070
150	2.864
158	3.861
CURVE 4*	
98	0.000
105	0.262
138	1.739
143	2.227
150	3.293
158	3.552
CURVE 5*	
98	0.000
105	-0.668
138	-2.80
143	-3.048
150	-3.415
158	-3.674
CURVE 6*	
293	0.00
1293	1.24
CURVE 7*	
293	0.00
1293	1.05
CURVE 8*	
293	0.000
1273	1.274
CURVE 9*	
293	0.000
1273	1.234
CURVE 10*	
293	0.000
1273	1.265
CURVE 11*	
300	0.010
800	0.740
CURVE 12*	
293	0.000
1293	1.163
CURVE 13*	
293	0.00
1293	0.99
CURVE 14*	
78	-0.527
139	-0.404
187	-0.337
228	-0.213
260	-0.086
293	0.000
327	0.130
374	0.267
CURVE 15*	
293	0.00
1293	1.54
CURVE 16*	
293	0.00
1293	1.29
CURVE 17*	
295	0.000
308	0.004
CURVE 18*	
319	0.008
337	0.014
CURVE 19*	
293	0.00
1293	1.43
CURVE 20*	
293	0.000
1293	1.209
CURVE 21*	
300	0.008
800	0.598
CURVE 22*	
297	0.006
323	0.046
373	0.123
423	0.188
473	0.232
523	0.284
573	0.326
623	0.376
673	0.421
695	0.439
718	0.417
735	0.407
CURVE 23*	
297	0.004
323	0.030
373	0.079
423	0.124
473	0.174
523	0.227
573	0.276
623	0.330
673	0.380
695	0.401
718	0.357
CURVE 24*	
297	0.008
323	0.061
373	0.163
423	0.262
473	0.035
515	-0.055
523	-0.053
573	0.034
623	0.143
673	0.253
695	0.300
718	0.271
737	0.255
CURVE 25*	
303	0.0108
335	0.0374
365	0.0772
402	0.125
432	0.165
503	0.280
546	0.354
CURVE 26	
1141	0.764
1181	0.810
1303	0.951
1391	1.103
1420	1.087
1499	1.196
CURVE 26 (cont.)	
1538	1.216
1609	1.331
1652	1.381
CURVE 27	
293	0.000
1223	0.939
CURVE 28	
273	-0.020
1273	1.000
CURVE 29*	
293	0.000
373	0.103
473	0.239
573	0.397
596	0.450
612	0.504
CURVE 30*	
286	-0.008
373	0.108
473	0.238
761	0.378

* Not shown in figure.

FIGURE AND TABLE NO. 339R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF CADMIUM TELLURIDE CdTe



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Powdered		Hot-Pressed, Irtran 6	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
10			-0.078	-0.7
25	-0.066	-2.7	-0.081	-2.0
50	-0.076	-1.8	-0.085	-1.2
75	-0.078	0.1	-0.086	1.0
100	-0.075	1.4	-0.082	2.3
150	-0.059	3.1	-0.065	3.8
200	-0.040	4.1	-0.045	4.4
250	-0.020	4.7	-0.022	4.9
293	0.000	4.9	0.000	5.3
300	0.003	5.0	0.004	5.3
350	0.028	5.1	0.032	5.7
400	0.053	5.1	0.062	6.0
450	0.080	5.2	0.093	6.2
500	0.107	5.3	0.124	6.3
525	0.121	5.3	0.140	6.3
550	0.134	5.3		
600	0.162	5.4		
650	0.189	5.5		
700	0.215	5.7		

REMARKS

The recommended values are based on the data for high-purity powdered samples (curves 1 and 9) and for hot pressed samples (curves 5 and 8). These values are considered accurate to within ± 5% and are represented approximately by the following equations:

Powdered: $\Delta L/L_0 = -9.802 \times 10^{-2} + 1.624 \times 10^{-4}\ T + 7.176 \times 10^{-7}\ T^2 - 4.445 \times 10^{-10}\ T^3$ (100-700 K)

Irtran 6: $\Delta L/L_0 = -0.102 + 1.031 \times 10^{-4}\ T + 1.027 \times 10^{-6}\ T^2 - 6.593 \times 10^{-10}\ T^3$ (100-525 K)

The tabulated values for the coefficient of thermal expansion are primarily derived from the selected experimental data and are considered accurate to about ± 10%.

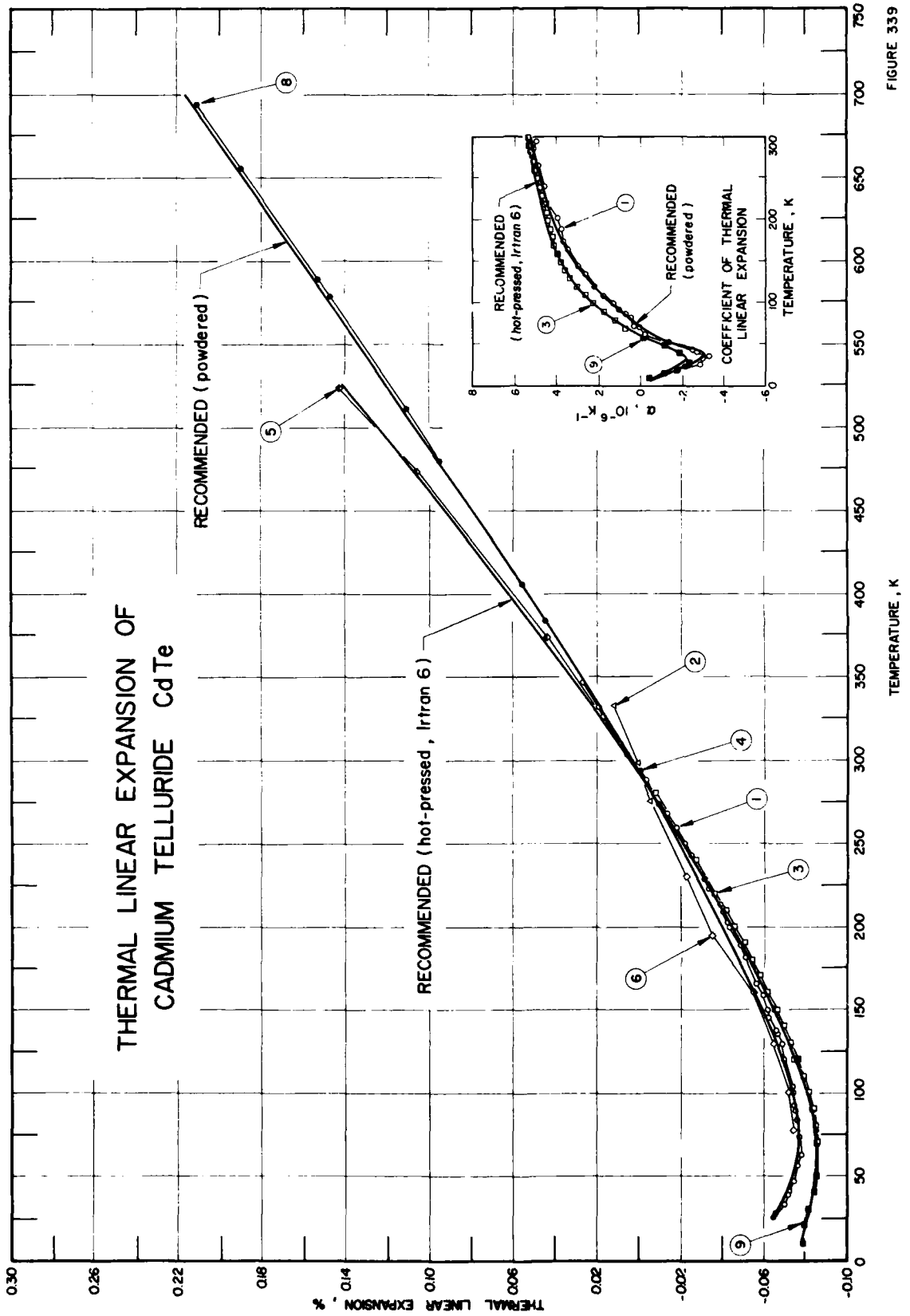

THERMAL LINEAR EXPANSION OF
CADMIUM TELLURIDE CdTe
RECOMMENDED (powdered)
RECOMMENDED (hot-pressed , Irtran 6)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
RECOMMENDED (hot-pressed , Irtran 6)
RECOMMENDED (powdered)

FIGURE 339

SPECIFICATION TABLE 339. THERMAL LINEAR EXPANSION OF CADMIUM TELLURIDE CdTe

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	939	Novikova, S.I.,	1961	L	25-346		Specimen prepared from spectrographically pure elements, specimen in form of irregular agglomeration of crystals with largest dimension 3.20 mm; data are compilation of results of six series of measurements.
2	148	Ballard, S.S. and Browder, J.S.	1966	I	273-333	Irtran 6	Infrared optical material, microcrystalline, hot-pressed compact by Eastman Kodak Company of New York; transmittance at 25 C, 1.5 μ to 31 μ; density 5.85 g/cc; reported error < 2%.
3	149, 904	Browder, J.S. and Ballard, S.S.	1969	E	70-310	Irtran 6	Microcrystalline, hot-pressed compact developed by the Eastman Kodak Company of Rochester, N.Y.
4	940	Pollock, D.B.	1969	L	77-293	Irtran 6	Similar to the above specimen; differential expansion, 3.2 cm long specimen; change in length of the fused silica taken as zero.
5	941	Ladd, L.S.	1966	L	298-523		Data averaged from eleven commercially available hot-pressed specimens.
6	160	Schaake, H.F.	1969	X	77-300		Specimen from Semi-Elements, powder ground to < 325 mesh, 10% Ir added for calibration, pressed into copper specimen holder; lattice parameter reported at 300 K as 6.4809 Å; 6.4807 Å at 293 K determined by graphical interpolation.
7*	942	Greenough, R.D. and Dalmer, S.B.	1972	S	57-100		Single crystals grown in Physics Department at University of Hull, York, England, in form of large plates in (110) plane; reported error is about 3%; anomaly in coefficient of thermal linear expansion is reported by authors to be due to the ionicity of the sample; this curve is here reported using the first given temperature as the reference temperature at which $\Delta L/L_0 = 0$.
8	945	Williams, M.G., Tomlinson, R.D., and Hampshire, M.J.	1969	X	293-693		99.9999 CdTe, obtained from Koch Light Laboratories Ltd., England, as small pieces, was crushed to pass through a 325 mesh screen, placed in 0.5 mm quartz capillary tube, expansion measured along a-axis; lattice parameter reported at 293 K as 6.4809 Å.
9	904	Browder, J.S. and Ballard, S.S.	1972	E	10-300		Microcrystalline, hot-pressed compact developed by Eastman Kodak Company of Rochester, N.Y.

* Not shown in figure.

DATA TABLE 339. THERMAL LINEAR EXPANSION OF CADMIUM TELLURIDE CdTe

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1‡

T	$\Delta L/L_0$
25	-0.067
27	-0.068
34	-0.070
37	-0.071
42	-0.072
46	-0.073
53	-0.075
63	-0.076
64	-0.076
71	-0.076
72	-0.076
83	-0.075
88	-0.075
92	-0.074
100	-0.073
103	-0.073
110	-0.072
117	-0.071
120	-0.070
127	-0.068
135	-0.066
137	-0.066
145	-0.063
149	-0.062
158	-0.059
165	-0.056
176	-0.052
181	-0.051
189	-0.048
199	-0.044
203	-0.042
209	-0.040
213	-0.038
221	-0.034
227	-0.032
228	-0.031
241	-0.025
250	-0.021
257	-0.018
267	-0.013
272	-0.011
282	-0.006
287	-0.003
295	0.001
302	0.005

CURVE 1 (cont.)‡

T	$\Delta L/L_0$
310	0.009
317	0.012
326	0.017
331	0.019
341	0.024
346	0.027

CURVE 2

T	$\Delta L/L_0$
273	-0.005
298	0.001
333	0.011

CURVE 3‡

T	$\Delta L/L_0$
70	-0.086
80	-0.085
90	-0.084
100	-0.082
110	-0.079
120	-0.076
130	-0.073
140	-0.070
150	-0.066
160	-0.062
170	-0.058
180	-0.054
190	-0.050
200	-0.045
210	-0.041*
220	-0.036
230	-0.032*
240	-0.027
250	-0.022*
260	-0.017
270	-0.012
280	-0.007
290	-0.002*
300	0.004*
310	0.009*

CURVE 4

T	$\Delta L/L_0$
77	-0.085
293	0.000

CURVE 5

T	$\Delta L/L_0$
298	0.0028
373	0.044
473	0.106
523	0.143

CURVE 6

T	$\Delta L/L_0$
77.4	-0.074
100.0	-0.072
130.0	-0.065
160.0	-0.055
194.5	-0.035
230.0	-0.022
300.0	0.002

CURVE 7*, †, ‡

T	$\Delta L/L_0$
57.6	0.00×10^{-1}
58.0	-0.14
58.0	-0.14
58.3	-0.23
58.6	-0.31
59.0	-0.42
59.4	-0.52
59.7	-0.59
59.8	-0.61
60.2	-0.68
60.5	-0.73
60.8	-0.78
61.2	-0.84
61.6	-0.90
62.0	-0.95
62.4	-0.98
63.0	-1.01
63.3	-1.01
63.6	-1.00
64.0	-0.99
66.6	-0.57
66.9	-0.49
67.3	-0.37
67.8	-0.21
68.4	-0.02
68.9	-0.15
69.6	-0.42
70.3	-0.71

CURVE 7 (cont.)*, †, ‡

T	$\Delta L/L_0$
70.8	0.95×10^{-4}
71.4	1.2
72.3	1.8
72.7	2.0
73.2	2.3
73.4	2.5
73.7	2.7
74.4	3.2
74.8	3.5
75.1	3.8
75.3	4.0
75.6	4.2
76.3	4.6
76.7	4.9
77.1	5.2
77.6	5.6
78.2	6.2
78.5	6.7
78.6	6.9
79.0	8.2
80.7	12.1
80.7	12.1
81.7	12.9
82.7	13.7
83.0	14.1
83.4	14.5
83.8	15.0
84.1	15.3
84.4	15.7
84.9	16.4
85.7	17.5
86.5	18.6
87.3	19.6
88.1	20.7
88.9	21.9
89.7	23.1
90.6	24.4
91.4	25.7
92.2	26.9
93.0	28.3
94.1	30.1
94.8	31.3
95.6	32.8
96.5	34.4
97.3	35.9

CURVE 7 (cont.)*, †, ‡

T	$\Delta L/L_0$
98.2	37.6×10^{-1}
99.3	39.8
100.0	41.1

CURVE 8‡

T	$\Delta L/L_0$
293	0.000*
383	0.045
405	0.056
479	0.095
511	0.111
578	0.147
588	0.153
655	0.190
693	0.211

CURVE 9‡

T	$\Delta L/L_0$
10	-0.079
15	-0.079*
20	-0.080
30	-0.082
40	-0.084
50	-0.086
60	-0.086*
70	-0.086
80	-0.085*
90	-0.084
100	-0.082*
110	-0.079*
120	-0.076
130	-0.073
140	-0.070*
150	-0.066
160	-0.062*
170	-0.058
180	-0.054*
190	-0.050*
200	-0.045
210	-0.041*
220	-0.036*
230	-0.031
300	0.003*

---

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 339. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CADMIUM TELLURIDE CdTe

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

CURVE 1‡

T	α
25	-2.13
27	-2.82
34	-3.00
37	-3.44
42	-2.71
46	-2.53
53	-1.34
63	0.02
64	-0.16*
71	0.03
72	0.39
83	0.49
88	0.70
92	1.06
100	1.31
103	1.56*
110	1.71
117	2.05*
120	2.20
127	2.38*
135	2.65
137	2.96*
145	3.00
149	3.36*
158	3.58*
165	3.55
176	3.69
181	3.88*
189	3.71
199	4.17*
203	3.91
209	4.17*
213	4.52*
221	4.42
227	4.25*
228	4.54*
241	4.65
250	4.84*
257	4.48*
267	4.86
272	5.09*
282	4.92*
287	5.15
295	5.02
302	5.14*

CURVE 1 (cont.)‡

T	α
310	4.93*
317	5.18*
326	5.05*
331	5.34*
341	4.96*
346	5.18*

CURVE 3‡

T	α
70	0.70
80	1.24
90	1.72
100	2.28
110	2.65
120	3.04
130	3.33
140	3.60
150	3.80
160	3.97*
170	4.11
180	4.23
190	4.33
200	4.45
210	4.50
220	4.60
230	4.70
240	4.80
250	4.90
260	5.00
270	5.10
280	5.20
290	5.30
300	5.30
310	5.40*

CURVE 7*,‡

T	α
57.6	-0.32
58.0	-0.36
58.0	-0.31
58.3	-0.29
58.6	-0.27
59.0	-0.27
59.4	-0.22
59.7	-0.26

CURVE 7 (cont.)*,‡

T	α
59.8	-0.19
60.2	-0.17
60.5	-0.13
60.8	-0.20
61.2	-0.14
61.6	-0.14
62.0	-0.10
62.4	-0.06
63.0	-0.04
63.3	0.00
63.6	0.05
64.0	0.03
66.6	0.29
66.9	0.26
67.3	0.32
67.8	0.32
68.4	0.34
68.9	0.38
69.6	0.38
70.3	0.45
70.8	0.50
71.4	0.54
72.3	0.63
72.7	0.65
73.2	0.68
73.4	0.73
73.7	0.69
74.4	0.74
74.8	0.88
75.1	0.81
75.3	0.71
75.6	0.69
76.3	0.60
76.7	0.63
77.1	0.90
77.6	0.95
78.2	1.04
78.5	2.26
78.6	2.60
79.0	3.74
80.7	0.84
80.7	0.76
81.7	0.75
82.7	0.98
83.0	1.15

CURVE 7 (cont.)*,‡

T	α
83.4	1.21
83.8	1.14
84.1	1.27
84.4	1.31
84.9	1.34
85.7	1.34
86.5	1.34
87.3	1.37
88.1	1.41
88.9	1.46
89.7	1.50
90.6	1.54
91.4	1.57
92.2	1.60
93.0	1.60
94.1	1.71
94.8	1.80
95.6	1.83
96.5	1.89
97.3	1.89
93.2	1.90
99.3	1.94
100.0	1.98

CURVE 8*,‡

T	α
293	4.96
383	5.08
405	5.11
479	5.23
511	5.29
578	5.42
588	5.44
655	5.57
693	5.67

CURVE 9‡

T	α
10	-0.47
15	-1.15
20	-1.74
30	-2.30
40	-1.93
50	-1.22
60	-0.18

CURVE 9 (cont.)‡

T	α
70	0.60*
80	1.24*
90	1.72*
100	2.28*
110	2.65*
120	3.04*
130	3.33*
140	3.60*
150	3.80*
160	3.97
170	4.11*
180	4.23*
190	4.33*
200	4.45*
210	4.53*
220	4.61*
230	4.70*
300	5.30*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

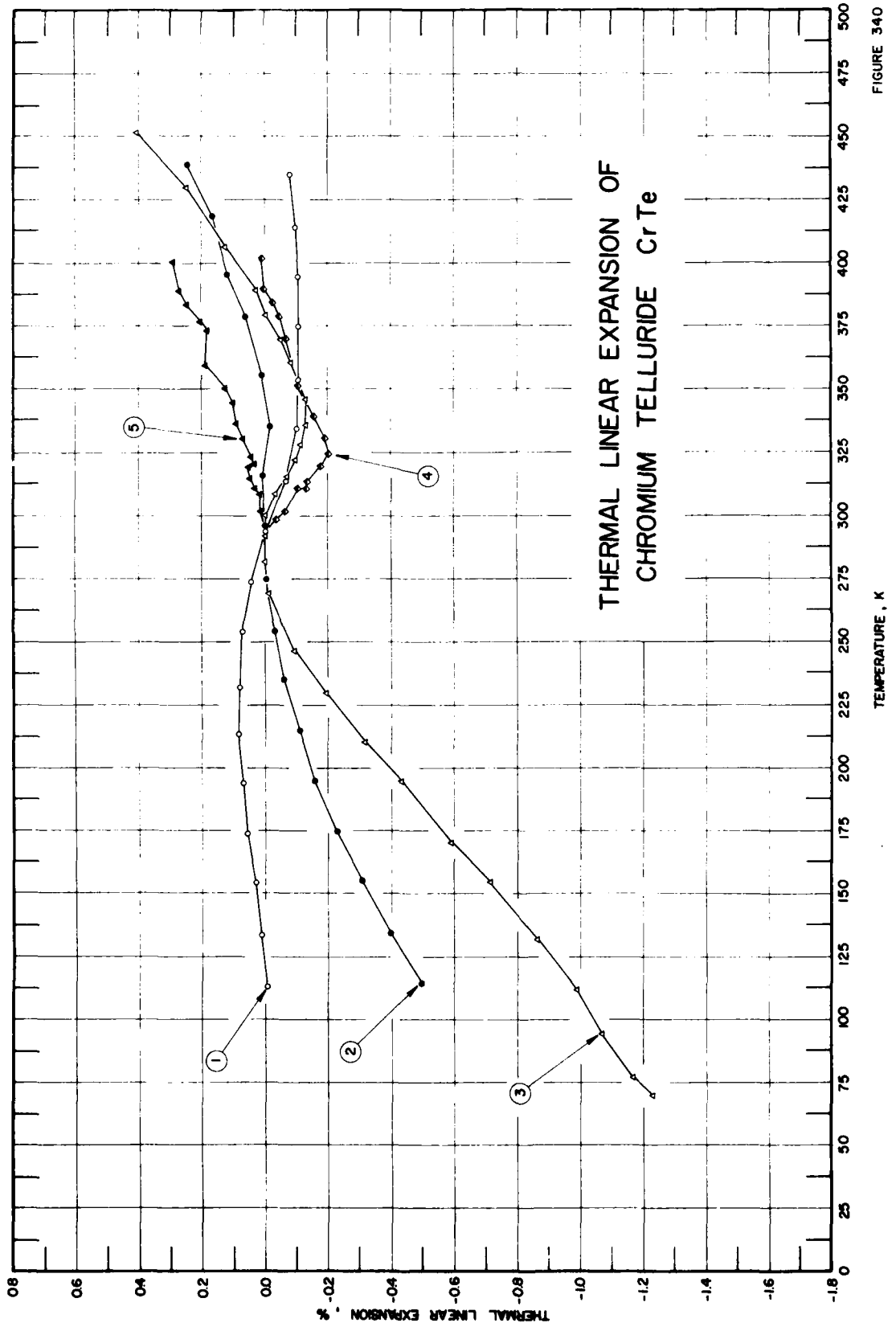

THERMAL LINEAR EXPANSION OF
CHROMIUM TELLURIDE Cr Te
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
1
2
3
4
5

FIGURE 340

SPECIFICATION TABLE 340. THERMAL LINEAR EXPANSION OF CHROMIUM TELLURIDE CrTe

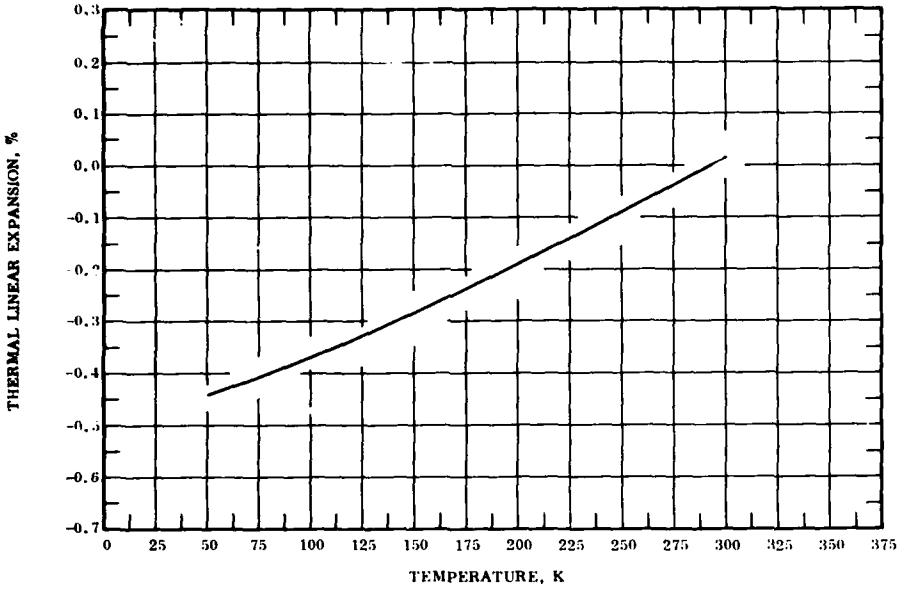
Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	943	Ido, H, Shirakawa, K., and Suzuki, T.	1969	X	113-436		99.9 Te; Cr, powder mixed in desired proportion, sealed in evacuated silica tube; heated at 1273 K for 7 days, cooled down slowly, crushed, mixed to homogenize, then melted at 1473 K for 40 min, cooled down to 1273 K, then quenched in water, sliced into disk 2 mm thickness, annealed in vacuum at 1173 K for 16 hr, quenched into water; lattice parameter reported at 293 K as 4.0558 Å; expansion measured along a-axis.
2	943	Ido, H., et al.	1969	X	114-438		Specimen cut from the same piece as the above specimen; lattice parameter reported at 293 K as 6.2427 Å; expansion measured along c-axis.
3	944	Galkin, A.A., Zavadskii, Z.A., and Sinel'nikov, B. Ya.	1971	X	69-452		Single crystal, single phase grown from sintered charge by Bridgman method; lattice parameter reported at 293 K as 6.268 Å; expansion measured at 0 K bar.
4	945	Gordienko, V.A., Zubenko, V.V., and Nikolaev, V.I.	1969	L	294-402		Powder sample; Curie point reported at 327 K; expansion measured along a-axis; lattice parameter reported at 293 K as 3.988 Å.
5	945	Gordienko, V.A., et al.	1969	L	294-401		The above specimen; expansion measured along c-axis; lattice parameter reported at 293 K as 6.214 Å; anomaly reported due to magnetic transition temperature.

DATA TABLE 340. THERMAL LINEAR EXPANSION OF CHROMIUM TELLURIDE CrTe

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3		CURVE 3 (cont.)		CURVE 4 (cont.)		CURVE 5 (cont.)	
113	-0.007	114	-0.496	69	-1.228	328	-0.112	313	-0.133	308	0.024
133	0.018	134	-0.399	77	-1.165	336	-0.128	319	-0.174	311	0.037
153	0.034	155	-0.306	94	-1.069	346	-0.128	324	-0.200	314	0.047
173	0.060	174	-0.229	112	-0.989	354	-0.112	331	-0.187	319	0.047
193	0.076	194	-0.158	132	-0.862	361	-0.080	338	-0.156	321	0.039
213	0.089	214	-0.107	154	-0.718	369	-0.048	345	-0.133	323	0.043
232	0.085	235	-0.059	170	-0.590	379	0.000	352	-0.105	331	0.071
253	0.079	254	-0.027	194	-0.431	389	0.032	359	-0.084	337	0.098
273	0.048	275	-0.005	210	-0.319	407	0.128	370	-0.061	344	0.103
293	0.000	293	0.000	229	-0.191	430	0.255	378	-0.043	351	0.129
313	-0.062	296	0.000	247	-0.096	452	0.415	384	-0.026	359	0.193
334	-0.100	316	-0.010	268	-0.016			390	0.005	373	0.183
353	-0.108	336	-0.016	282	0.000	CURVE 4		402	0.013	377	0.208
375	-0.107	356	0.016	291	0.000					383	0.249
395	-0.104	378	0.061	293	0.000	294	-0.008	CURVE 5		389	0.278
414	-0.095	398	0.120	300	0.000	297	-0.038			401	0.298
436	-0.079	418	0.171	308	-0.032	302	-0.061	294	-0.008		
		438	0.242	315	-0.064	311	-0.105	297	0.011		
				322	-0.096	311	-0.133	302	0.019		

FIGURE AND TABLE NO. 341R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF LEAD TELLURIDE PbTe



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
50	-0.445	13.6
75	-0.409	15.2
100	-0.370	16.5
120	-0.336	17.5
140	-0.300	18.2
160	-0.263	18.9
180	-0.225	19.4
200	-0.186	19.7
220	-0.146	19.9
240	-0.106	20.0
260	-0.066	20.2
280	-0.026	20.3
293	0.000	20.4
300	0.013	20.4

REMARKS

The recommended values are based on the data for pure samples. These values are considered accurate to within ± 5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.504 + 9.772 \times 10^{-4}\, T + 4.266 \times 10^{-6}\, T^2 - 5.922 \times 10^{-9}\, T^3$$

The tabulated values for the coefficient of thermal expansion are derived primarily by differentiating the above equation and are considered accurate to about ± 10%.

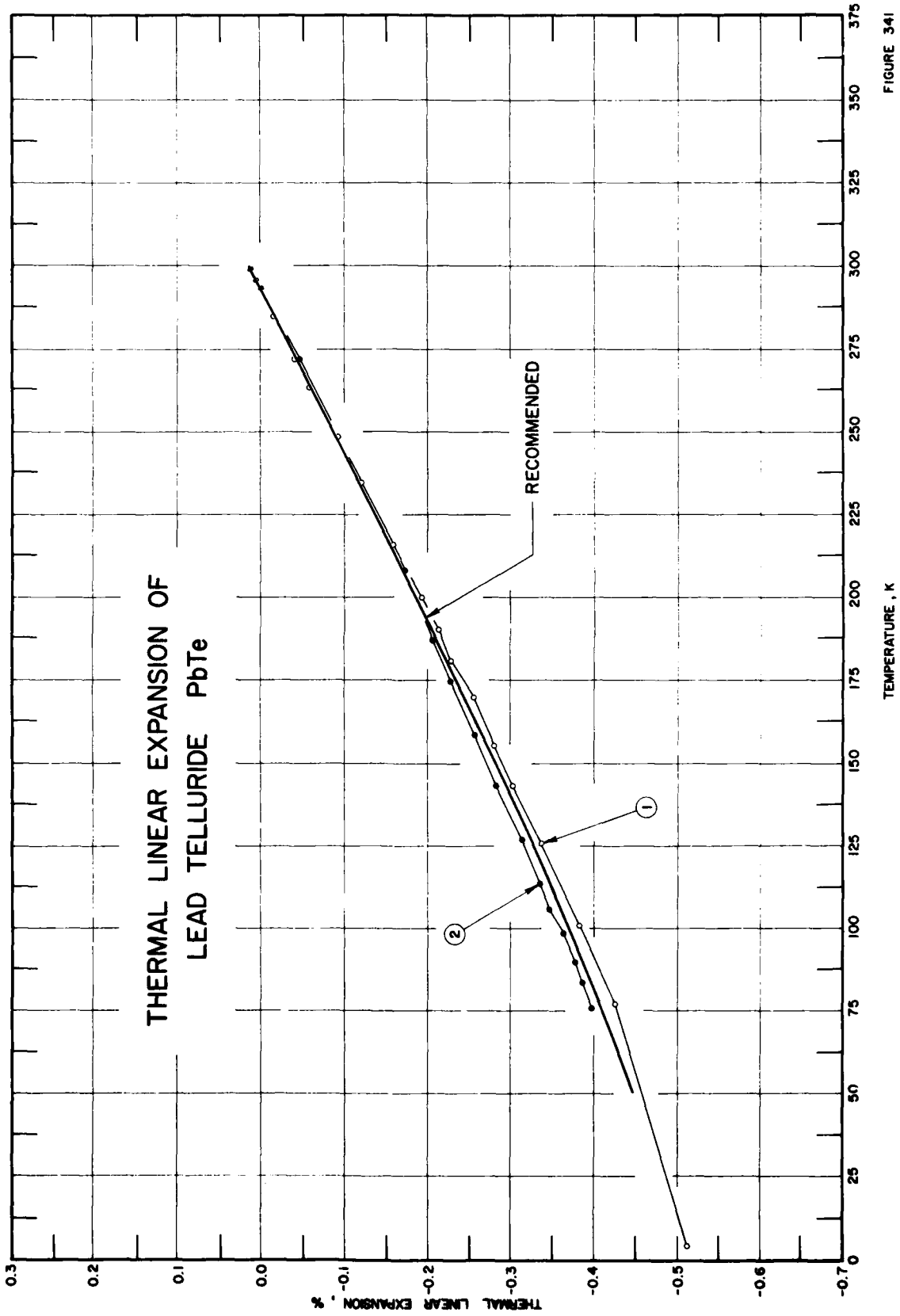

THERMAL LINEAR EXPANSION OF
LEAD TELLURIDE PbTe
RECOMMENDED
1
2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375

FIGURE 341

SPECIFICATION TABLE 341. THERMAL LINEAR EXPANSION OF LEAD TELLURIDE PbTe

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	951	Houston, B., Strakna, R.E., and Belson, H.S.	1968	E	4-296		Crystal grown using Czochralski technique; starting materials 99.999 percent pure Pb and Te; measured in a capacitative cell; calibrated using pure Al, Cu, and SiO_2 samples to measure thermal expansion of copper reference cylinder; zero-point correction is -0.510% at 293 K.
2	952	Hohnke, D.K., Holloway, H., and Kaiser, S.	1971	X	76-299		Particle size ~ 74 μm, powder; constituent purity: 99.9999 Pb and 99.9999 Te; sealed in evacuated silica tubes at ~ 10^{-6} torr, melted, shaken for complete mixing, quenched in ice water; resulting ignots crushed to powder and resealed in ampoules for annealing; layers of thickness 1-4 μm deposited by evaporating on single rod of spectroscopically pure graphite; annealing took place at 873 K 100 hr to establish equilibrium of specimen; lattice parameter reported at 293 K as 6.4617 Å.

DATA TABLE 341. THERMAL LINEAR EXPANSION OF LEAD TELLURIDE PbTe

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2	
4	-0.510	76	-0.399
77	-0.426	83	-0.387
101	-0.382	89	-0.378
126	-0.337	98	-0.362
143	-0.301	106	-0.347
155	-0.280	113	-0.336
169	-0.255	127	-0.313
181	-0.227	143	-0.282
190	-0.213	158	-0.257
200	-0.192	174	-0.227
216	-0.158	187	-0.207
234	-0.120	208	-0.172
248	-0.092	272	-0.045
263	-0.058	293	0.000
272	-0.040	299	0.012
284	-0.015		
296	0.006		

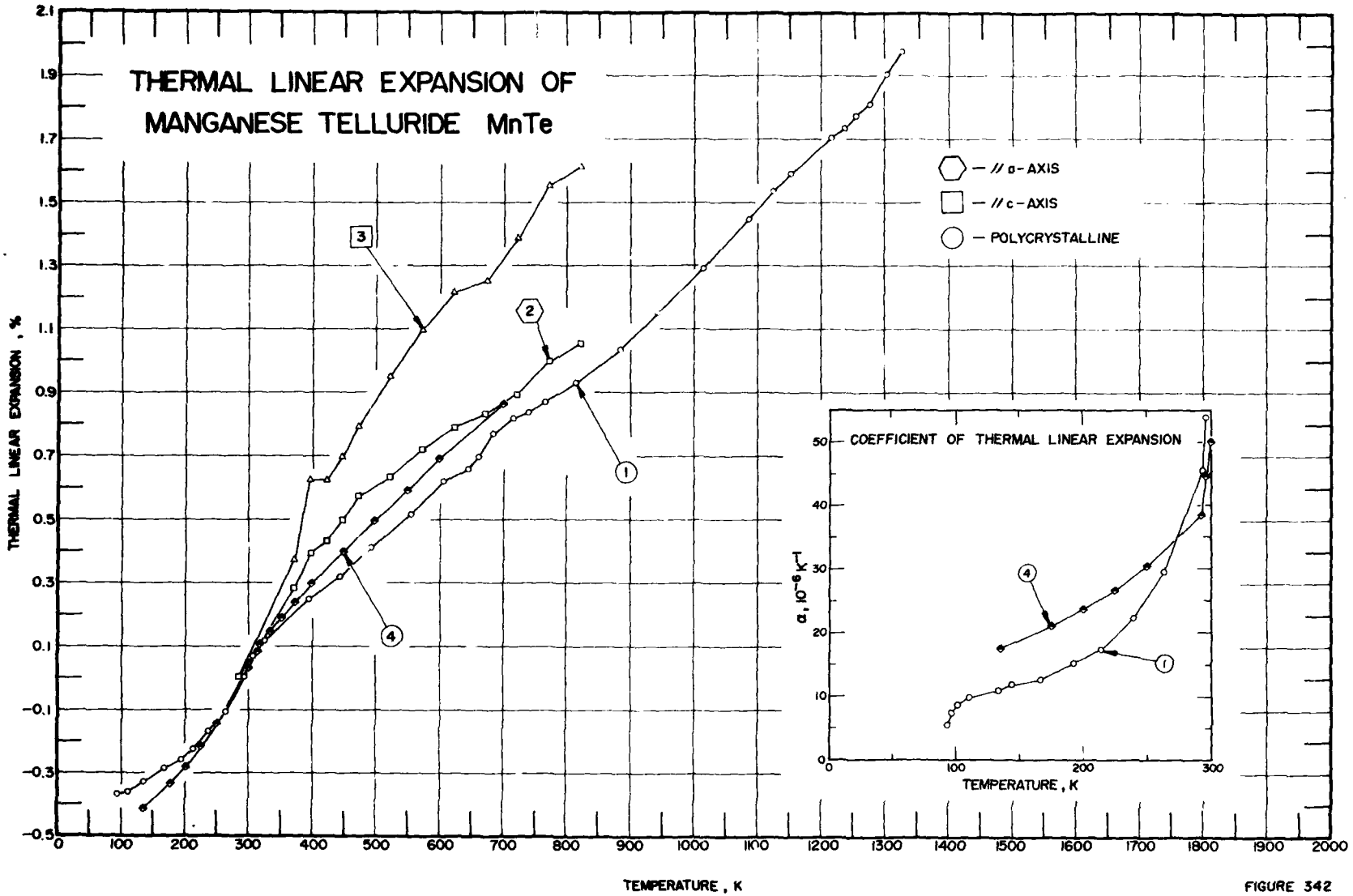

THERMAL LINEAR EXPANSION OF
MANGANESE TELLURIDE MnTe
— // a-AXIS
— // c-AXIS
— POLYCRYSTALLINE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K

FIGURE 342

SPECIFICATION TABLE 342. THERMAL LINEAR EXPANSION OF MANGANESE TELLURIDE MnTe

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	953	Abrikosov, N. Kh., Dyul'dina, K.A., and Zhdanova, V.V.	1968	L	93-1327		Stoichiometric composition (69.9% Te); prepared by fusing components in graphite crucibles, slow stepped heating from 673 K to 1473 K; mixed for 1 hr; annealed in sealed quartz vessel filled with argon; vacuum dilatometer UVD in an argon atmosphere.
2	954	Gronvold, I., Kveseth, N.J., Marques, F.D.S., and Tichy, J.	1971	X	293-823		99.999 Te (stated purity from American Smelting and Refining Co.), 99.995 Mn (stated purity from L. Light Co. of England), 0.0005 each Mg, Si, Mn flakes etched with dilute nitric acid to remove surface oxidation products, washed, dried and pumped and heated to 10^{-5} torr and 870 K until gas evolution ceased; Te + Mn mixture heated at 1070 K for 2 days in double walled tube, then annealed at 770 K for 30 days and cooled to room temperature; expansion measured along a-axis; lattice parameter reported at 293 K as 4.1429 Å.
3	954	Gronvold, I., et al.	1971	X	293-823		The above specimen; expansion measured along c-axis; lattice parameter reported at 293 K as 6.7076 Å.
4	955	Sirota, N.N. and Makovetskii, G.I.	1971	X	135-700		Reported anomaly was reported by author to be an antiferromagnetic transformation; data is off by a magnitude of 2 it appears; zero-point correction is -0.159% at 293 K.

DATA TABLE 342. THERMAL LINEAR EXPANSION OF MANGANESE TELLURIDE MnTe

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 1 (cont.)‡		CURVE 2		CURVE 3 (cont.)		CURVE 4 (cont.)‡	
93	-0.376	492	0.401	1086	1.441	293	0.000	448	0.690	300	0.031
97	-0.374*	555	0.511	1127	1.530	373	0.280	473	0.784	307	0.065*
102	-0.370*	616	0.617	1153	1.585	398	0.384	523	0.942	309	0.073*
110	-0.362	641	0.656	1218	1.707	423	0.422	573	1.096	311	0.081
133	-0.338	644	0.661*	1231	1.726*	448	0.488	623	1.209	318	0.103
144	-0.325*	656	0.688*	1239	1.738	473	0.567	673	1.273	333	0.145
167	-0.297	660	0.699	1255	1.776	523	0.632	723	1.382	351	0.188
192	-0.262	674	0.744*	1260	1.788*	573	0.717	773	1.550	373	0.236
213	-0.228	681	0.766	1279	1.809	623	0.782	823	1.610	400	0.293
239	-0.176	686	0.778*	1282	1.812*	673	0.826			450	0.396
263	-0.114	695	0.795*	1282	1.812*	723	0.893	CURVE 4‡		500	0.494
293	-0.001	699	0.801*	1284	1.818*	773	0.994			550	0.588
296	0.014*	718	0.819	1284	1.818*	823	1.050	135	-0.418	600	0.680
307	0.064	740	0.836	1285	1.823*			175	-0.340	700	0.864
314	0.087*	767	0.863	1303	1.908	CURVE 3		200	-0.284		
317	0.095*	786	0.885*	1309	1.931*			225	-0.221		
327	0.118	813	0.923	1309	1.931*	293	0.000*	250	-0.149		
344	0.151*	882	1.034	1327	1.975	373	0.366	293	0.000*		
396	0.242	943	1.146			398	0.540	296	0.013*		
441	0.317	1014	1.289			423	0.620	297	0.017*		

DATA TABLE 342. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MANGANESE TELLURIDE MnTe

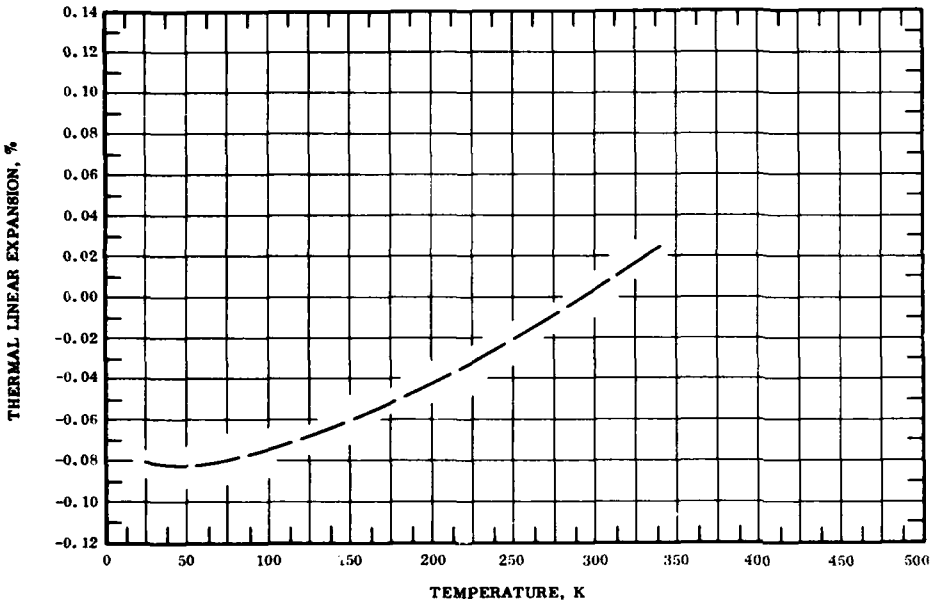
[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α	T	α	T	α
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 1 (cont.)‡		CURVE 1 (cont.)‡		CURVE 4 (cont.)‡		CURVE 4 (cont.)‡	
93	5.4	327	20.9*	718	6.5*	1279	2.5*	225	26.8	550	18.4*
97	7.5	344	17.9*	740	9.2*	1282	14.2*	250	30.6	600	18.4*
102	8.7	396	17.2*	767	10.8*	1282	25.4*	293	38.7	700	18.4*
110	9.9	441	16.1*	786	13.0*	1284	35.0*	296	44.9		
133	11.0	492	17.1*	813	14.8*	1284	44.7*	297	45.0*		
144	11.9	555	17.7*	882	17.5*	1285	54.1*	300	50.0		
167	12.8	616	17.2*	943	19.2*	1303	40.9*	307	45.0*		
192	15.1	641	14.0*	1014	20.9*	1309	34.5*	309	40.0*		
213	17.5	644	19.2*	1086	21.5*	1309	30.4*	311	35.0*		
239	22.3	656	24.9*	1127	21.5*	1327	18.3*	318	30.0*		
263	29.6	660	29.0*	1153	21.1*			333	25.0*		
293	45.7	674	35.3*	1218	16.4*	CURVE 4‡		351	22.8*		
296	54.0	681	28.5*	1231	12.6*			373	21.5*		
307	36.6*	686	21.3*	1239	18.5*	135	17.7	400	20.8*		
314	30.5*	695	15.9*	1255	29.2*	175	21.1	450	20.1*		
317	23.5*	699	12.2*	1260	19.4*	200	23.9	500	19.2*		

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 343R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF MERCURY TELLURIDE HgTe



PROVISIONAL VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

T	$\Delta L/L_0$	α
25	-0.080	-2.7
50	-0.083	0.0
75	-0.079	1.7
100	-0.074	2.3
125	-0.068	2.8
150	-0.060	3.2
175	-0.052	3.6
200	-0.042	4.0
225	-0.032	4.3
250	-0.021	4.6
275	-0.009	4.8
293	0.000	5.0
300	0.003	5.1
320	0.014	5.2
340	0.024	5.4

REMARKS

The provisional values are based on the data for high-purity samples by giving more weight to the most recent measurements. These values are considered accurate to within ± 7% at temperatures above 200 K and ± 10% below 200 K. The provisional values are represented approximately by the following equation:

$$\Delta L/L_0 = -8.695 \times 10^{-2} + 1.597 \times 10^{-5}\, T + 1.217 \times 10^{-6}\, T^2 - 8.853 \times 10^{-10}\, T^3 \qquad (50\text{-}340\ K)$$

The tabulated values for the coefficient of thermal expansion are derived primarily from the selected experimental data and are considered accurate to about ± 15%.

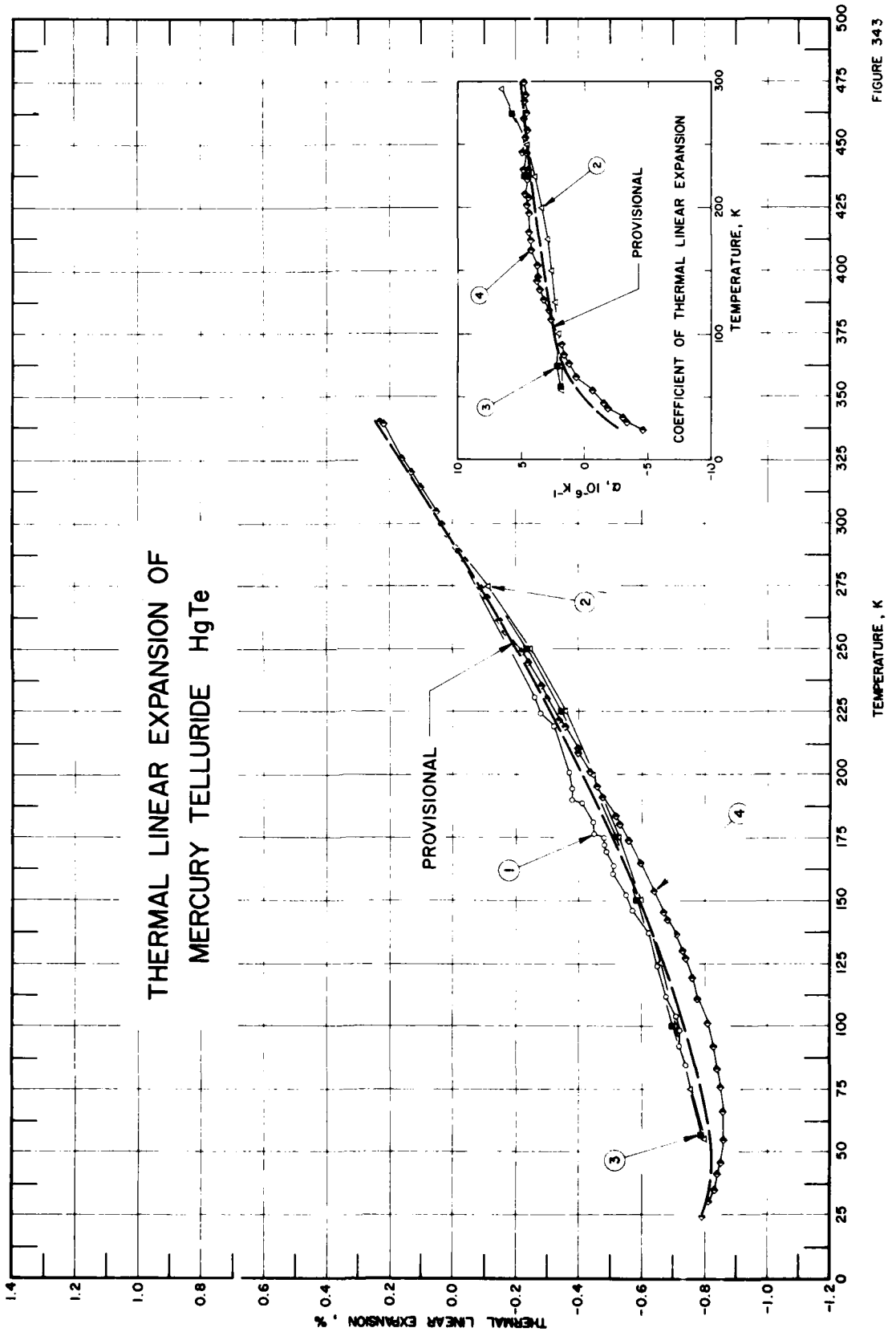

THERMAL LINEAR EXPANSION OF
MERCURY TELLURIDE HgTe
PROVISIONAL
PROVISIONAL
COEFFICIENT OF THERMAL LINEAR EXPANSION
α, 10⁻⁶ K⁻¹
TEMPERATURE, K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K

FIGURE 343

SPECIFICATION TABLE 343. THERMAL LINEAR EXPANSION OF MERCURY TELLURIDE HgTe

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	956	Sniadower, L., Psoda, M., and Galazka, R. R.	1968	X	84-291		Monocrystalline sample; dimension 12 x 15 x 2 mm^3; optically polished; reflex from the (660) plane; lattice parameter reported at 291 K as 6.4605 Å; 6.46058 Å at 293 K determined by graphical extrapolation.
2	957	Alper, T. and Saunders, G. A.	1967	L	55-295	HgTe + Te	96 HgTe, 4 Te; single crystal grown from 99.999 pure elements; specimen 2.5 cm in diameter and 2 cm long; reported error 4-8%.
3	957	Alper, T. and Saunders, G. A.	1967	X	57-293		Single crystal, dimension cylindrical 2.5 cm diameter x 2 cm length grown from 99.999 purity elements by technique of directional freezing of melts of composition; $Hg_{1.00}Te_{1.12}$ in evacuated quartz tubes; reported error 7%.
4	958	Novikova, S. J. and Abrikosov, Abrikosov, N. Kh.	1964	L	24-341		Specimen prepared from 99.99 Hg; 99.99 Te pure components, coarsely crystalline and irregular form, longest dimension 12.89 mm.

DATA TABLE 343. THERMAL LINEAR EXPANSION OF MERCURY TELLURIDE HgTe

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 3‡		CURVE 4 (cont.)‡		CURVE 4 (cont.)‡		CURVE 4 (cont.)‡	
84	-0.074	201	-0.037	57	-0.079	56	-0.106	173	-0.076	271	-0.011
92	-0.072	218	-0.032	100	-0.071	66	-0.106	180	-0.073	275	-0.009
98	-0.072	224	-0.028	125	-0.065*	76	-0.105	183	-0.072	285	-0.004
103	-0.071	231	-0.026	150	-0.059	83	-0.104	191	-0.068	289	-0.002
112	-0.068	291	-0.001	175	-0.052	92	-0.102	195	-0.059	299	0.003
123	-0.065			200	-0.044*	101	-0.100	201	-0.044	304	0.005
137	-0.062	CURVE 2‡		225	-0.035	101	-0.093	208	-0.041	313	0.010
146	-0.057			250	-0.024	111	-0.099	210	-0.040	320	0.013
152	-0.055	55	-0.080	275	-0.011*	119	-0.096	218	-0.036	326	0.016
161	-0.051	75	-0.076	293	-0.000*	119	-0.096	222	-0.034	339	0.022
163	-0.051	100	-0.071			127	-0.094	230	-0.030	341	0.023
168	-0.049	125	-0.066	CURVE 4‡		130	-0.093	230	-0.030		
172	-0.048	150	-0.060			136	-0.091	235	-0.028		
175	-0.048	175	-0.053	24	-0.099	142	-0.089	244	-0.024		
176	-0.045	200	-0.045	30	-0.101	145	-0.087	244	-0.024		
182	-0.045	225	-0.036	34	-0.102	153	-0.084	248	-0.022		
188	-0.041	250	-0.025	41	-0.104	154	-0.084	257	-0.017		
190	-0.038	275	-0.012	45	-0.105	164	-0.080	257	-0.017		
194	-0.038	295	0.001	55	-0.106	166	-0.079	262	-0.015		

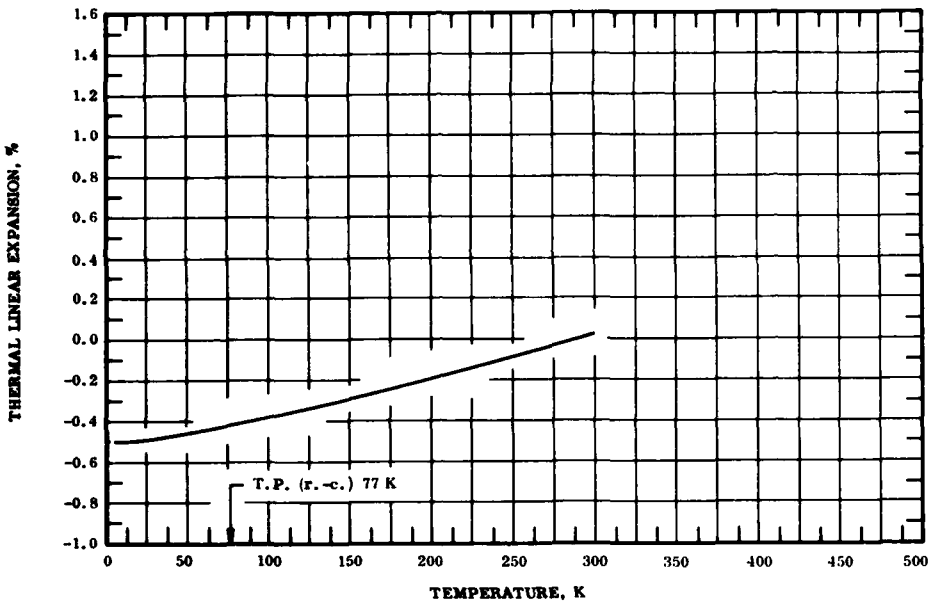
DATA TABLE 343. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MERCURY TELLURIDE HgTe

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α	T	α	T	α
CURVE 2‡		CURVE 3 (cont.)‡		CURVE 4 (cont.)‡		CURVE 4 (cont.)‡		CURVE 4 (cont.)‡		CURVE 4 (cont.)‡	
55	1.80	125	2.33	55	-0.66	153	3.83	235	4.77	339	4.66
75	1.92	150	2.59	56	-0.52	154	4.01	244	4.77	341	4.84
100	2.11	175	2.95	66	0.69	164	4.05	244	4.93		
125	2.34	200	3.34	76	1.26	166	4.22	248	4.75		
150	2.60	225	3.98	83	1.59	173	4.29	257	4.75		
175	2.92	250	4.76	92	1.90	180	4.29	257	4.96		
200	3.37	275	5.73	101	2.13	183	4.40	262	4.67		
225	3.99	293	6.60	101	2.53	191	4.46	271	4.91		
250	4.78			111	2.61	195	4.46	275	4.74		
275	5.72	CURVE 4‡		119	2.85	201	4.62	285	4.84		
295	6.76			119	3.12	208	4.58	289	4.79		
CURVE 3‡		24	-4.07	127	3.12	210	4.73	299	4.83		
		30	-3.34	130	3.32	218	4.62	304	4.83		
57	1.80	34	-3.06	136	3.61	222	4.68	313	4.83		
100	2.09	41	-1.99	142	3.80	230	4.62	320	4.62		
		45	-1.64	145	3.71	230	4.89	326	4.83		

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 344R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF TIN TELLURIDE SnTe



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
5	-0.494	0.5
10	-0.493	1.3
20	-0.491	3.4
25	-0.489	5.1
50	-0.460	13.0
68	-0.434	16.1
75	-0.424	12.7
77†	-0.421	11.2
90	-0.403	17.5
100	-0.385	17.9
150	-0.293	19.3
200	-0.192	20.4
250	-0.087	20.9
293	0.000	21.3
300	0.014	21.4

† Transition from rhombohedral to cubic structure.

REMARKS

The recommended values are based on the data for high-purity samples and are considered accurate to within ± 3%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.512 + 7.660 \times 10^{-4}\, T + 5.974 \times 10^{-6}\, T^2 - 8.953 \times 10^{-9}\, T^3 \qquad (25\text{-}300\ K)$$

The tabulated values for the coefficient of thermal expansion are derived primarily from the selected experimental data and are considered accurate to about ± 5%.

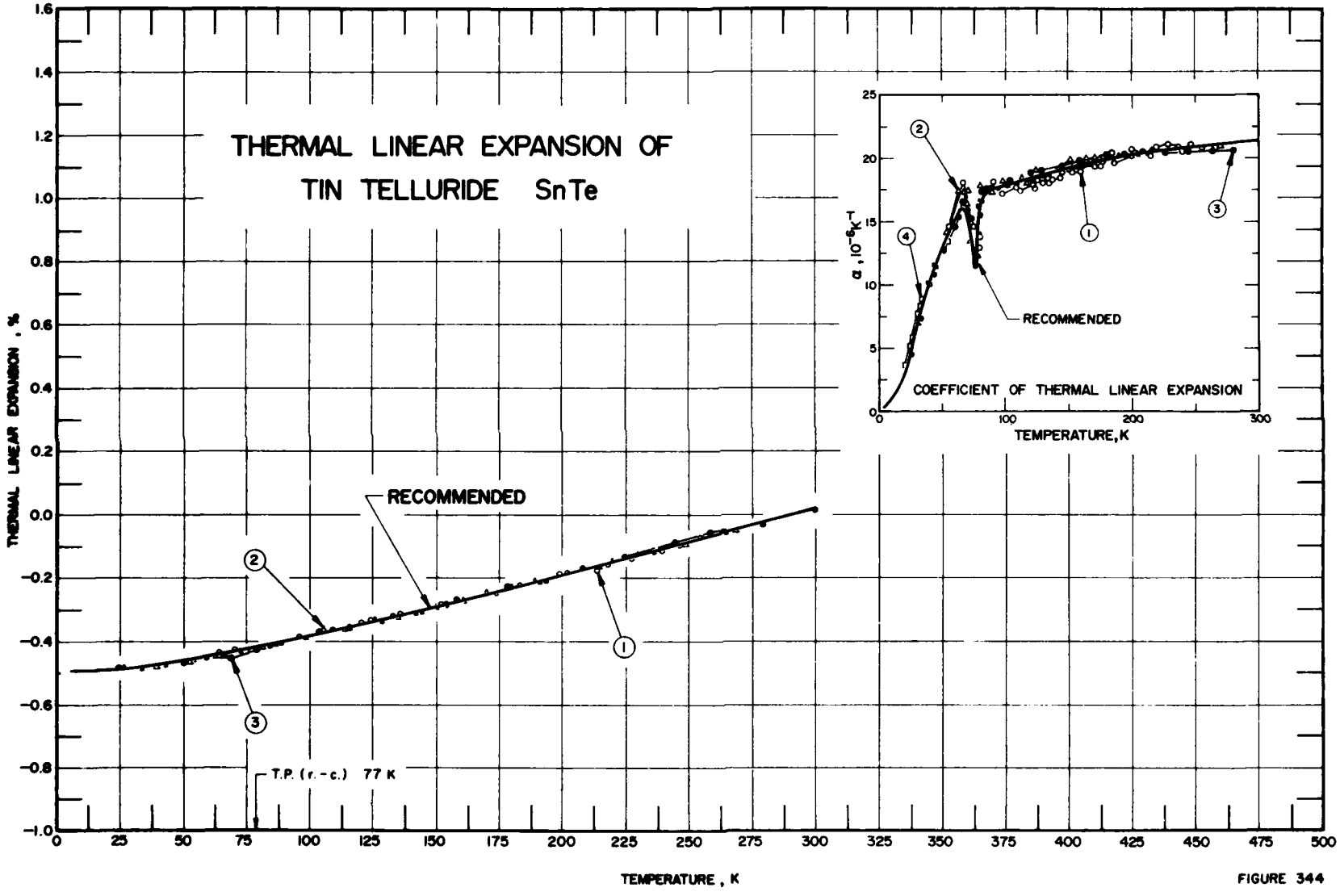

THERMAL LINEAR EXPANSION OF
TIN TELLURIDE SnTe
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED
T.P. (r.-c.) 77 K
1
2
3
4
α , 10⁻⁶K⁻¹
COEFFICIENT OF THERMAL LINEAR EXPANSION
TEMPERATURE, K

FIGURE 344

SPECIFICATION TABLE 344. THERMAL LINEAR EXPANSION OF TIN (II) TELLURIDE SnTe

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	959	Novikova, S.I. and Shelimova, L.E.	1967	L	18-264		50.4 Te; single crystal grown by Bridgman technique; 99.98 pure Te and high purity tin with 10^{-3} percent impurity; specimen cut out of the central region of the single crystal; 8 series of measurements along direction perpendicular to the three-fold axis; transition temperature ~ 77 K from rhombohedral to cubic structure; reported error 2.5-3.5%.
2	959	Novikova, S.I. and Shelimova, L.E.	1967	L	24-269		The above specimen; measured along direction parallel to the three-fold axis.
3	960	Novikova, S.I. and Shelimova, L.E.	1966	L	25-301		52.2 Te (50.4 at.%) and 47.8 Sn; two cylindrical specimens 16.07, and 10.86 mm long; high purity tin with $< 10^{-3}$ percent impurity, A-1 tellurium purified by double vacuum distillation; prepared by melting components in evacuated quartz ampoules and cooled in air; one annealed at 773 K for 500 hr, the other not; seven series of measurements on two specimens; measurements under constant temperature conditions; reported error ±2%.
4*	960	Novikova, S.I. and Shelimova, L.E.	1966	L	4-53		The above specimen; measurements under varying temperature condition; this curve is here reported using 4 K as reference temperature at which $\Delta L/L_0 = 0$.
5*	961	Belson, H.S. and Houston, B.	1970	E	54-96		50.4% Te and 99.999 pure Sn melted in evacuated silica bond; nearly single crystal formed; this curve is here reported using 4 K as reference temperature at which $\Delta L/L_0 = 0$.
6*	961	Belson, H.S. and Houston, B.	1970	E	4-86		Similar to the above specimen; except of low carrier concentration about 10^{20} carriers/cm^3; this curve is here reported using 4 K as reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

DATA TABLE 344. THERMAL LINEAR EXPANSION OF TIN (II) TELLURIDE SnTe

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
24	-0.488*
25	-0.487*
35	-0.480*
36	-0.480*
46	-0.469*
50	-0.464*
56	-0.456
66	-0.439
68	-0.436*
72	-0.429
73	-0.427*
75	-0.424*
78	-0.421*
79	-0.419*
79	-0.419*
79	-0.419*
79	-0.419*
80	-0.418*
80	-0.418*
81	-0.416*
81	-0.416*
81	-0.416*
82	-0.415*
83	-0.413*
84	-0.411*
84	-0.411*
84	-0.411*
87	-0.406*
87	-0.406*
91	-0.399*
91	-0.399*
97	-0.388
98	-0.387*
100	-0.383*
109	-0.367*
110	-0.365*
112	-0.362*
114	-0.358*
117	-0.353
119	-0.349*
122	-0.344
124	-0.341
126	-0.337*
130	-0.330*
134	-0.322
135	-0.321*
135	-0.321

T	$\Delta L/L_0$
CURVE 1 (cont.)‡	
137	-0.317
143	-0.306
145	-0.302*
145	-0.302*
148	-0.296
150	-0.292*
153	-0.287
155	-0.283
159	-0.275*
161	-0.271*
161	-0.271*
171	-0.252*
174	-0.246
175	-0.244*
184	-0.226
186	-0.222*
186	-0.222*
192	-0.210
200	-0.193
200	-0.193
203	-0.187
210	-0.173*
214	-0.165
218	-0.157
222	-0.148*
228	-0.136
237	-0.117
240	-0.111
247	-0.096
256	-0.077
266	-0.056
CURVE 2‡	
24	-0.493*
24	-0.493*
31	-0.489
34	-0.486*
40	-0.481
43	-0.477*
53	-0.465
54	-0.464*
63	-0.449
67	-0.442
70	-0.437
70	-0.437*
71	-0.436*

T	$\Delta L/L_0$
CURVE 2 (cont.)‡	
73	-0.433
73	-0.433*
74	-0.431*
78	-0.426
78	-0.426*
78	-0.426*
78	-0.426*
79	-0.425*
79	-0.425*
80	-0.423*
81	-0.422*
81	-0.422*
82	-0.420
83	-0.418*
84	-0.417*
84	-0.417*
87	-0.411
90	-0.406*
90	-0.406*
90	-0.406*
94	-0.399*
99	-0.390*
99	-0.390
101	-0.386*
101	-0.386*
107	-0.376
109	-0.372*
111	-0.368*
114	-0.363
114	-0.363*
120	-0.352*
123	-0.347
123	-0.347*
125	-0.343*
127	-0.339*
127	-0.339
130	-0.333*
134	-0.326*
136	-0.322
139	-0.316*
146	-0.303*
147	-0.301*
151	-0.293*
151	-0.293
153	-0.289*
155	-0.285*

T	$\Delta L/L_0$
CURVE 2 (cont.)‡	
160	-0.275*
162	-0.271
164	-0.268*
166	-0.264*
171	-0.254
174	-0.247*
176	-0.243*
181	-0.233
185	-0.225*
189	-0.217*
190	-0.215
198	-0.199*
203	-0.188*
215	-0.164
221	-0.151
225	-0.143*
231	-0.130
249	-0.093
269	-0.051
CURVE 3‡	
25	-0.488
33	-0.483
43	-0.474
51	-0.465
60	-0.452
62	-0.450
67	-0.442
70	-0.437
73	-0.432
80	-0.421
80	-0.421
81	-0.420
82	-0.418
85	-0.412
89	-0.406
105	-0.377
120	-0.349
129	-0.332
145	-0.301
158	-0.276
179	-0.234
194	-0.204
208	-0.175
226	-0.138

T	$\Delta L/L_0$
CURVE 3 (cont.)‡	
245	-0.099
264	-0.060
281	-0.025
301	0.016
CURVE 4*,‡,§	
4	0.000
22	0.003
25	0.005
27	0.000
31	0.008
34	0.011
35	0.012
40	0.016
46	0.023
53	0.031
CURVE 5*,§	
54.1	42.0×10^{-3}
54.3	42.5
55.0	43.6
56.2	45.1
57.0	46.7
58.5	49.0
60.9	52.3
62.7	54.7
64.0	56.9
65.1	58.7
66.1	60.7
68.0	63.2
71.2	68.2
71.7	69.1
74.0	72.7
76.0	76.1
79.2	81.3
79.6	82.2
86.0	94.7
87.7	98.0
90.3	103.3
91.8	106.1
94.3	111.1
96.9	116.1

T	$\Delta L/L_0$
CURVE 6*,§	
4.0	0.0×10^{-3}
7.8	0.0
9.7	0.0
10.9	0.0
15.8	0.5
18.6	1.5
21.0	2.5
23.5	3.6
26.5	5.5
29.3	7.8
30.3	9.4
33.3	11.8
38.0	17.2
41.3	20.7
44.3	24.4
45.5	26.6
47.8	29.9
50.8	34.0
52.9	36.7
55.3	40.0
58.1	45.0
60.4	48.0
62.9	51.0
65.3	54.7
68.7	60.2
72.1	65.3
74.0	68.3
77.3	73.8
80.6	79.0
82.4	81.9
82.8	83.2
83.2	84.5
86.2	89.9

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

§ This curve is here reported using 4.0 K as reference temperature at which $\Delta L/L_0$ 0.

DATA TABLE 344. COEFFICIENT OF THERMAL LINEAR EXPANSION OF TIN (II) TELLURIDE SnTe

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

CURVE 1‡

T	α
24	4.44*
25	5.25*
35	8.20*
36	9.36*
46	11.94*
50	13.11*
56	14.55
66	18.01
68	18.24*
72	16.33*
73	14.82*
75	14.56
78	10.46*
79	12.93
79	13.85
79	14.33*
79	15.18*
80	14.75*
80	15.51*
81	16.38*
81	16.09*
81	17.00*
82	15.83*
83	16.62*
84	17.35*
84	17.84*
84	16.99*
87	17.48*
87	17.94*
91	17.69*
91	18.11*
97	17.73*
98	17.23
100	17.48*
109	17.69
110	18.00*
112	17.48
114	17.91*
117	17.70*
119	17.89*
122	17.89
124	17.52
126	18.26
130	18.04
134	18.49
135	18.01

CURVE 1 (cont.)‡

T	α
135	18.88
137	18.31
143	18.92
145	18.74*
145	18.91
148	19.27*
150	19.27
153	18.93
155	19.28*
159	18.95
161	19.46
161	20.01*
171	19.40
174	19.96*
175	19.40*
184	20.40
186	19.64
186	19.94*
192	20.38*
200	20.25
200	20.71
203	20.04*
210	20.69*
214	20.20
218	20.84
222	20.44*
228	21.08
237	20.94
240	20.55
247	21.07
256	20.92
266	20.92

CURVE 2‡

T	α
24	4.4*
24	5.0*
31	7.1
34	8.0*
40	10.5*
43	11.6*
53	13.4*
54	14.2
63	17.4
67	17.3
70	16.5

CURVE 2 (cont.)‡

T	α
70	17.4
71	15.2*
73	15.3*
73	13.4
74	13.1*
78	12.3
78	15.5*
78	14.6*
78	15.2*
79	16.2*
79	14.2
80	14.5*
81	17.0*
81	17.0
82	16.7*
83	17.1*
84	17.5*
84	17.8*
87	17.5*
90	17.3
90	17.5*
90	17.9*
94	17.7
99	17.7*
99	18.2
101	17.9
101	17.5*
107	18.1*
109	18.2
111	18.2*
114	18.4
114	17.9
120	18.2
123	18.9
123	18.5
125	18.6*
127	18.9*
127	18.4*
130	18.6
134	19.2*
136	19.2*
139	18.9*
146	19.3*
147	19.6*
151	19.9

CURVE 2 (cont.)‡

T	α
151	19.6*
153	19.7*
155	19.4
160	19.7*
162	20.0
164	19.7*
166	20.0*
171	20.0
174	20.3*
176	20.0*
181	20.4*
185	20.1*
189	20.1
190	20.5*
198	20.7*
203	20.4
215	20.6
221	21.1*
225	20.8*
231	20.8*
249	21.0*
269	21.1

CURVE 3‡

T	α
25	4.5
33	7.3
43	10.8
51	12.8
60	14.6
62	15.3
67	16.6
70	16.0
73	15.2
80	15.6
80	16.3
81	16.9
82	17.3
85	17.6
89	17.7
105	18.2
120	18.8
129	19.0
145	19.4
158	19.8

CURVE 3 (cont.)‡

T	α
179	20.2
194	20.2
208	20.5
226	20.5
245	20.6
264	20.6
281	20.7
301	20.6

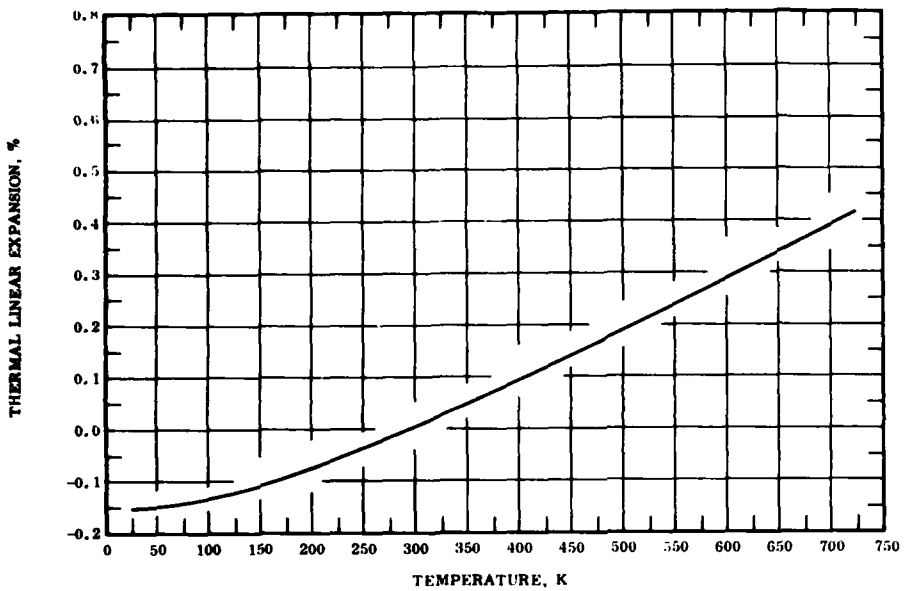
CURVE 4‡

T	α
4	0.4
22	3.7
25	5.1
27	5.9
31	7.7
34	8.3
35	8.8
40	10.1
46	11.5
53	13.5

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0 = 0$.

FIGURE AND TABLE NO. 345R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF ZINC TELLURIDE ZnTe



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
25	-0.150	-0.7
50	-0.150	0.2
75	-0.147	2.7
100	-0.140	4.2
150	-0.109	6.4
200	-0.073	7.7
250	-0.035	8.4
293	0.000	8.7
300	0.006	8.8
350	0.049	9.0
400	0.093	9.1
450	0.139	9.3
500	0.186	9.5
550	0.235	9.7
600	0.284	10.0
650	0.334	10.2
700	0.384	10.5
725	0.410	10.7

REMARKS

The recommended values are based on the data for high-purity samples and are considered accurate to within ± 3% at temperatures below 400 K and ± 5% above 400 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.200 + 5.104 \times 10^{-4}\, T + 6.811 \times 10^{-7}\, T^2 - 3.104 \times 10^{-10}\, T^3 \qquad (100\text{-}725\ K)$$

The tabulated values for the coefficient of thermal expansion are based primarily on the selected experimental data and are considered accurate to about ± 7%.

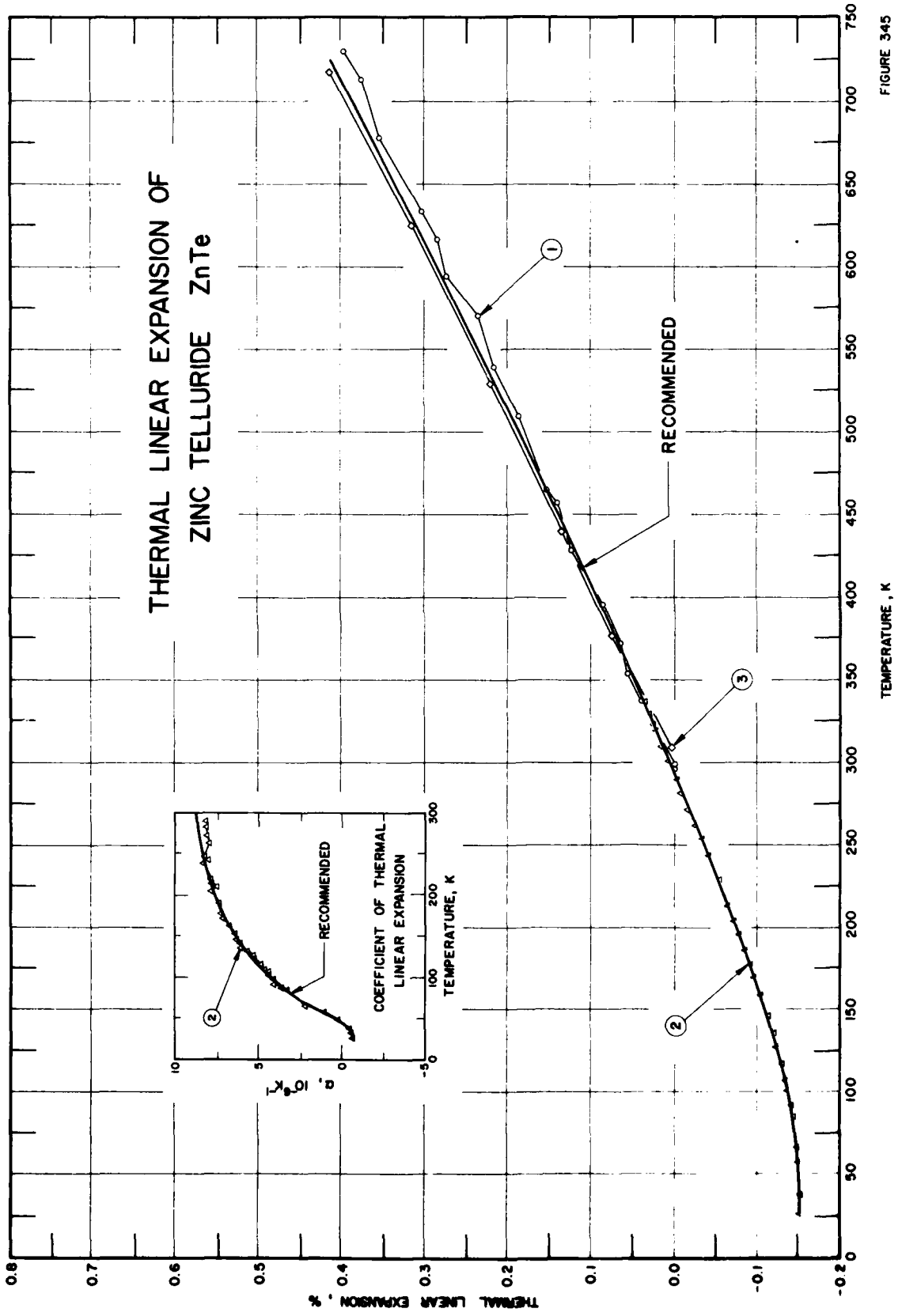

THERMAL LINEAR EXPANSION OF
ZINC TELLURIDE ZnTe
RECOMMENDED
1
2
3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
α, 10⁻⁶K⁻¹
TEMPERATURE, K

FIGURE 345

SPECIFICATION TABLE 345 THERMAL LINEAR EXPANSION OF ZINC TELLURIDE ZnTe

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	962	Holland, H.J. and Beck, K.	1968	X	296-731		0.001 Fe impurity; platinum (99.991 percent) added as an internal standard; diffractometer using CuKα, radiation; four back-reflection zinc telluride [(531), (620), (533), and (711)] and three platinum [(400), (331), and (420)] diffraction lines used; measured in helium atmosphere; lattice parameter reported at 293 K as 6.1026 Å.
2	958	Novikova, S.I. and A[illegible]ov, N.Kh.	1964	L	27-337		Specimen prepared from quite pure zinc and 99.99 pure Te, coarsely crystalline and irregular form, longest dimension 9.27 mm.
3	872	S[illegible]h, H.P. and Dayal, B.	1969	X	308-718		Ultra pure sample annealed at 529 K for 4 hr; lattice parameter reported at 293 K is 6.1026 Å; coefficient of thermal linear expansion also reported.

DATA TABLE 345. THERMAL LINEAR EXPANSION OF ZINC TELLURIDE ZnTe

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2‡		CURVE 2 (cont.)‡		CURVE 2 (cont.)‡		CURVE 3 (cont.)	
296	0.000	27	-0.150	146	-0.114	243	-0.041	625	0.315
299	0.000	33	-0.150	149	-0.112	248	-0.037	718	0.411
323	0.026	38	-0.151	154	-0.108	253	-0.033		
337	0.040	49	-0.151	158	-0.106	262	-0.026		
353	0.057	58	-0.150	162	-0.103	272	-0.017		
371	0.065	67	-0.149	168	-0.099	282	-0.009		
396	0.085	85	-0.144	171	-0.097	291	-0.002		
428	0.121	88	-0.143	177	-0.092	301	0.007		
457	0.140	92	-0.141	179	-0.091	309	0.013		
464	0.154	98	-0.139	186	-0.086	319	0.022		
509	0.188	101	-0.137	189	-0.084	329	0.030		
539	0.216	107	-0.135	195	-0.079	337	0.037		
570	0.237	110	-0.133	199	-0.076				
593	0.273	116	-0.130	204	-0.072	CURVE 3			
616	0.285	123	-0.127	211	-0.067				
633	0.301	128	-0.124	213	-0.065	308	0.015		
678	0.355	133	-0.121	220	-0.060	376	0.077		
713	0.376	136	-0.120	229	-0.052	440	0.136		
731	0.399	142	-0.116	238	-0.045	529	0.221		

DATA TABLE 345. COEFFICIENT OF THERMAL LINEAR EXPANSION OF ZINC TELLURIDE ZnTe

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α
CURVE 2‡		CURVE 2 (cont.)‡		CURVE 2 (cont.)‡		CURVE 2 (cont.)‡	
27	-0.68	128	5.27	195	7.49	301	8.43
33	-0.60	133	5.73	199	7.66	309	8.43
38	-0.50	136	6.02	204	7.79	319	8.50
49	0.20	142	6.14	211	7.59	329	8.38
58	1.08	146	6.35	213	7.92	337	8.57
67	2.26	149	6.64	220	7.98		
85	3.39	154	6.49	229	8.07	CURVE 3	
88	3.63	158	6.71	238	8.28		
92	4.11	162	6.76	243	8.13	308	9.03
98	4.11	168	6.84	248	8.30	376	9.21
101	4.45	171	7.17	253	8.07	440	9.40
107	4.45	177	7.26	262	8.00	529	9.70
110	4.74	179	7.44	272	8.16	625	10.06
116	4.94	186	7.38	282	8.28	718	10.46
123	5.27	189	7.49	291	8.25		

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

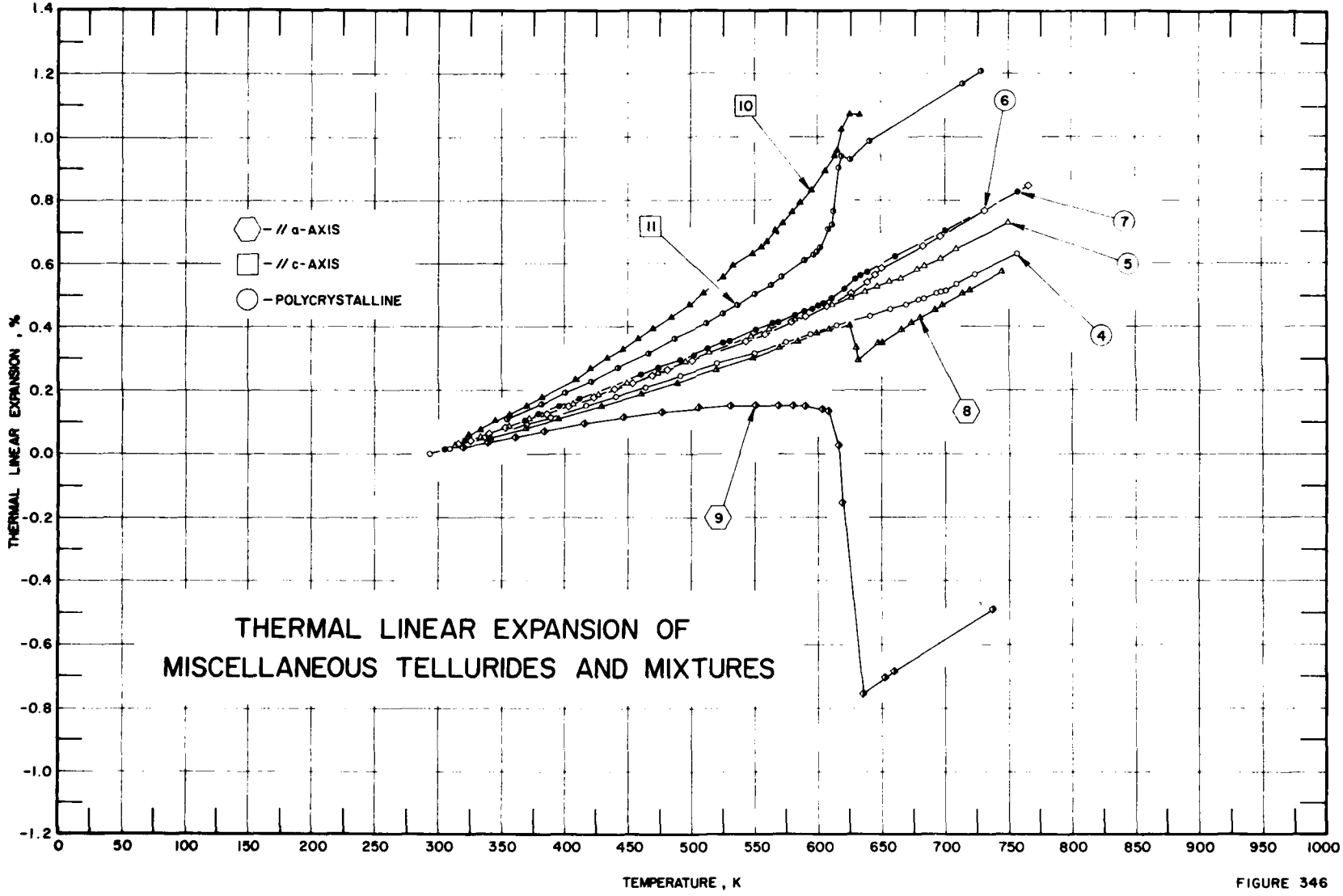

THERMAL LINEAR EXPANSION OF
MISCELLANEOUS TELLURIDES AND MIXTURES
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
// a-AXIS
// c-AXIS
POLYCRYSTALLINE
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
10
6
11
7
5
4
8
9

FIGURE 346

SPECIFICATION TABLE 346. THERMAL LINEAR EXPANSION OF MISCELLANEOUS TELLURIDES AND MIXTURES

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	938	Francombe, M.H.	1958	X	78-647	Bi_2Te_3	Bismuth tritelluride; powdered, single-crystal material obtained from zone-melted ingots, prepared from zone-refined bismuth and tellurium, powder specimen annealed in evacuated, sealed, vitreous silica tube for 4 to 6 days at 693 K; lattice parameter reported at 293 K as 4.3821 Å; expansion measured along a-axis.
2*	938	Francombe, M.H.	1958	X	78-647	Bi_2Te_3	Bismuth tritelluride; the above specimen; expansion measured along c-axis; lattice parameter reported at 293 K as 30.491 Å.
3*	946	Novikova, S.I.	1966	L	25-336	$CuInTe_2$	Copper indium telluride; 99.99% pure, in polycrystalline; dimension cylinder; 16.76 mm long; data from four sects of measurements.
4	947	Shelimova, L.E., Abrikosov, N.Kh., and Zhdanova, V.V.	1965	L	293-757	GeTe	Germanium telluride; 63.73 Te and 36.27 Ge; specimen prepared from 99.996+ pure materials; Ge and Te melted together in evacuated quartz ampoules after complete mixing; cooled in air, annealed 520 hr at 773 K in Ar atmosphere, then 70 hr at 673 K, 960 hr at 573 K, and 850 hr at 523 K; finally annealed 110 hr at 873 K and tempered by immersion in ice-water; change in coefficient of expansion near 653 K coincides with melting of eutectics and to near-isothermal change from rhombohedral to cubic structure.
5	947	Shelimova, L.E., et al.	1965	L	293-750	GeTe	Germanium telluride; 63.46 Te and 36.54 Ge; similar to the above specimen; 0.277 excess Te.
6	947	Shelimova, L.E., et al.	1965	L	315-766	GeTe	Germanium telluride; 63.18 Te and 36.82 Ge; similar to the above specimen; 0.553 excess Te.
7	947	Shelimova, L.E., et al.	1965	L	305-757	GeTe	Germanium telluride; 62.62 Te and 37.38 Ge; similar to the above specimen; 1.102 excess Te.
8	948, 949	Novikova, S.I., Shelimova, L.E., Abrikosov, N.Kh., and Evseev, B.A. Evseev, B.A.	1970	L	293-745	GeTe	Germanium telluride; 63.73 Te and 36.27 Ge; dimension; rectangular, 6.8 x 7.3 x 5.9 mm single crystal; grown by the Bridgman-Stockbarger method from a melt; phase transition reported at 629 K on heating (from rhombohedral to NaCl type f.c.c.) and 619 K on cooling; expansion measured along a-axis on heating cycle; data seems to be off by a factor of 10 with respect to reference 949, TPRC, changed reported values by a factor of 10.
9	948, 949	Novikova, S.I., et al.	1970	L	737-293	GeTe	Germanium telluride; the above specimen; expansion measured along a-axis during cooling cycle.
10	948	Novikova, S.I., et al.	1970	L	293-633	GeTe	Germanium telluride; the above specimen; expansion measured along c-axis on heating cycle.
11	948	Novikova, S.I., et al.	1970	L	728-354	GeTe	Germanium telluride; the above specimen; expansion measured along c-axis on cooling cycle.
12*	523	Novikova, S.I.	1969	L	26-351	In_2Te_3	Indium telluride; polycrystalline specimen prepared from 99.999 pure elements; data compilation of four series of measurements.
13*	950	Eliseev, A.A., Kuznetsov, V.G., and Yarembash, E.I.	1967	X	293, 573	LaTe	Lanthanum telluride; dimension cylindrical; 0.3 mm diameter x 6-8 mm long; polycrystalline, cubic face-centered NaCl structure type; ground and screened powder vacuum-fused at 10^{-3} mm Hg into a thin-walled quartz capillary with walls ~ 0.02 mm thick.
14*	950	Eliseev, A.A., et al.	1967	X	293, 573	$La_{3-x}Te_4$	Lanthanum telluride; similar to the above specimen; cubic body-centered Th_3P_4 structural type.

* Not shown in figure.

SPECIFICATION TABLE 346. THERMAL LINEAR EXPANSION OF MISCELLANEOUS TELLURIDES AND MIXTURES (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
15*	950	Eliseev, A.A., Kuznetsov, V.G., and Yarembash, E.I.	1967	X	293, 573	$LaTe_2$	Lanthanum telluride; similar to the above specimen; pulverized monocrystals, Cu_2Sb structure type, measured parallel to [001] direction.
16*	950	Eliseev, A.A., et al.	1967	X	293, 573	$LaTe_{3-x}$	Lanthanum telluride; similar to the above specimen; polycrystalline specimen, tetragonal structure, measured perpendicular to [001] direction.
17*	952	Hohnke, D.K., Holloway, H., and Kaiser, S.	1971	X	50-298	$Pb_{0.98}Ge_{0.02}Te$	Lead germanium telluride; particle size ~ 74 μm; powder; constituent purity; 99.9999 Pb, 99.9999 Te; sealed in evacuated silica tubes ~ 10^{-6} Torr, melted, shaken for complete mixing, quenched in ice water; resulting ignots, crushed to powder and resealed in ampoules for annealing; layers of thickness 1-4 μm deposited by evaporating on a single rod of spectroscopically pure graphite; annealing took place at 873 K for 100 hr to establish equilibrium of specimen; semiconductor grade Ge used; lattice parameter reported at 293 K as 6.4522 Å.
18*	952	Hohnke, D.K., et al.	1971	X	84-299	$Pb_{0.953}Ge_{0.047}Te$	Lead germanium telluride; similar to the above specimen; different composition; lattice parameter reported at 293 K as 6.4400 Å.
19*	952	Hohnke, D.K., et al.	1971	X	99-298	$Pb_{0.925}Ge_{0.075}Te$	Lead germanium telluride; similar to the above specimen; different composition; lattice parameter reported at 293 K as 6.4279 Å.
20*	963	Johnson, R.G.R.	1962		298-784	Sb_2Te_3 + 0.05 In_2Te_3	61.18 Te, 36.98 Sb, 1.84 In; specimen prepared by induction melting in a graphite crucible at 1023 K in a Balzers furnace under an argon atmosphere, cast the melt onto a carbon-coated water-cooled copper mold, hand crushing these chill cast ingots to -60 mesh powder in a steel mortar and pestle; cold pressed at 35 tsi in graphite-lubricated carbide-lined still dies, and then sintered at 773 K for 3 hr in argon; measured with the increasing temperature.
21*	963	Johnson, R.G.R.	1962		784-298	Sb_2Te_3 + 0.05 In_2Te_3	The above specimen measured with decreasing temperature.

* Not shown in figure.

DATA TABLE 346. THERMAL LINEAR EXPANSION OF MISCELLANEOUS TELLURIDES AND MIXTURES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
78	-0.290
102	-0.258
121	-0.233
173	-0.167
215	-0.119
250	-0.064
273	-0.032
293	0.000
355	0.078
408	0.153
447	0.194
492	0.246
560	0.342
614	0.424
647	0.486

CURVE 2*

T	$\Delta L/L_0$
78	-0.466
112	-0.394
174	-0.259
293	0.000
349	0.134
384	0.220
436	0.357
487	0.518
534	0.626
596	0.754
647	0.853

CURVE 3*,‡

T	$\Delta L/L_0$
25	-0.1677
29	-0.1681
34	-0.1686
42	-0.1690
53	-0.1685
63	-0.1668
75	-0.1633
89	-0.1576
90	-0.1572
99	-0.1529
101	-0.1519
104	-0.1503
105	-0.1498
112	-0.1459

CURVE 3 (cont.)*,‡

T	$\Delta L/L_0$
118	-0.1424
121	-0.1406
127	-0.1370
128	-0.1363
131	-0.1344
131	-0.1344
138	-0.1298
143	-0.1263
148	-0.1228
154	-0.1183
155	-0.1176
157	-0.1161
169	-0.1068
171	-0.1053
176	-0.1013
178	-0.0997
187	-0.0924
194	-0.0867
196	-0.0850
204	-0.0782
208	-0.0748
212	-0.0714
212	-0.0714
221	-0.0636
231	-0.0549
232	-0.0540
243	-0.0442
246	-0.0416
250	-0.0380
257	-0.0319
267	-0.0232
270	-0.0205
277	-0.0143
286	-0.0063
288	-0.0045
300	0.0064
302	0.0082
306	0.0118
319	0.0237
324	0.0282
335	0.0384
336	0.0393

CURVE 4‡

T	$\Delta L/L_0$
293	-0.000

CURVE 4 (cont.)‡

T	$\Delta L/L_0$
309	0.019
336	0.052
370	0.094
389	0.117
417	0.152
440	0.180
463	0.209
491	0.244
520	0.281
550	0.319
575	0.351
594	0.375
614	0.401
641	0.436
657	0.457
669	0.472
678	0.484
683	0.491
693	0.506
696	0.511
698	0.514
700	0.518
709	0.536
724	0.566
757	0.632

CURVE 5‡

T	$\Delta L/L_0$
293	0.000*
313	0.027
333	0.055
356	0.087
372	0.110
407	0.160
426	0.188
449	0.222
474	0.259
495	0.291
514	0.319
547	0.370
561	0.392
582	0.425
611	0.471
626	0.495
637	0.512
647	0.529

CURVE 5 (cont.)‡

T	$\Delta L/L_0$
657	0.545
665	0.558
678	0.581
683	0.591
685	0.595*
696	0.618
709	0.645
750	0.730

CURVE 6‡

T	$\Delta L/L_0$
315	0.030
325	0.043
340	0.064
353	0.082
373	0.110*
386	0.128
404	0.153
423	0.180
439	0.203
453	0.223
469	0.246
482	0.265
501	0.293
513	0.310*
543	0.356
558	0.379
563	0.387*
580	0.416
591	0.435
607	0.464
610	0.470*
626	0.503
627	0.505*
639	0.541
645	0.565
651	0.585
683	0.658
696	0.687
732	0.767
766	0.843

CURVE 7‡

T	$\Delta L/L_0$
305	0.017
322	0.043

CURVE 7 (cont.)‡

T	$\Delta L/L_0$
333	0.059*
356	0.093*
368	0.111
379	0.127
395	0.151
412	0.177
427	0.199*
438	0.216*
460	0.249
474	0.271
491	0.296
502	0.313
513	0.330
525	0.348
530	0.356
551	0.389
564	0.409
568	0.415
582	0.438
589	0.449
595	0.459
600	0.468
601	0.470*
604	0.476
611	0.492
621	0.522
629	0.551
633	0.563
639	0.576
661	0.623
700	0.705
731	0.771*
757	0.826

CURVE 8‡

T	$\Delta L/L_0$
293	0.000*
312	0.021*
340	0.053
368	0.083
395	0.113
428	0.152
460	0.189
488	0.223
520	0.263
549	0.302

CURVE 8 (cont.)‡

T	$\Delta L/L_0$
571	0.336
584	0.356
599	0.379
609	0.393
614	0.399*
616	0.401*
625	0.402
627	0.401*
630	0.339
632	0.295
630	0.298*
630	0.298*
630	0.298*
649	0.347
651	0.354
666	0.393
667	0.396*
673	0.412
680	0.428
692	0.455
698	0.469
714	0.506
720	0.520
745	0.579

CURVE 9‡

T	$\Delta L/L_0$
737	-0.490
659	-0.684
652	-0.702
635	-0.759
619	-0.153
616	0.027
611	0.131*
608	0.135
603	0.140
597	0.145*
590	0.150
580	0.155
568	0.157
550	0.156
532	0.152
505	0.143
477	0.131
447	0.116
416	0.096

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 346. THERMAL LINEAR EXPANSION OF MISCELLANEOUS TELLURIDES AND MIXTURES (continued)

T	$\Delta L/L_0$
CURVE 9 (cont.)‡	
384	0.074
361	0.057
339	0.039
319	0.023
293	0.000*
CURVE 10‡	
293	0.000*
307	0.027*
324	0.060
333	0.079
345	0.103
356	0.125
369	0.153
382	0.181
408	0.239
420	0.268
434	0.301
446	0.331
458	0.362
470	0.394
484	0.434
498	0.475
510	0.511
526	0.560
538	0.599
548	0.634
555	0.659
560	0.678
567	0.706
573	0.731
580	0.762
587	0.796
595	0.836
606	0.897
613	0.944*
613	0.944
615	0.962*
615	0.962*
615	0.962*
615	0.962
618	1.031*
618	1.031*
618	1.031*
618	1.031*
618	1.031
625	1.076

T	$\Delta L/L_0$
CURVE 10 (cont.)‡	
625	1.076*
625	1.076*
633	1.073*
633	1.073*
633	1.073
CURVE 11‡	
728	1.207
714	1.173
641	0.984
625	0.929
625	0.929*
621	0.938*
618	0.935*
617	0.929*
618	0.941
616	0.902
616	0.902*
612	0.762
612	0.762*
611	0.726
611	0.726*
608	0.712
602	0.651
602	0.651*
602	0.651*
602	0.651*
599	0.640
597	0.633
591	0.615*
589	0.609
572	0.560
563	0.535
550	0.501
537	0.468
525	0.441
512	0.413
487	0.361
466	0.318
442	0.271
420	0.229
400	0.192
382	0.159
354	0.109

T	$\Delta L/L_0$
CURVE 12*,‡	
26	-0.228
31	-0.227
36	-0.225
45	-0.221
56	-0.216
62	-0.212
72	-0.206
86	-0.195
88	-0.194
93	-0.190
101	-0.184
102	-0.183
108	-0.178
112	-0.175
117	-0.171
119	-0.169
124	-0.165
128	-0.161
137	-0.153
138	-0.152
146	-0.145
151	-0.141
155	-0.137
163	-0.130
166	-0.127
173	-0.120
181	-0.112
186	-0.107
191	-0.103
200	-0.094
210	-0.084
220	-0.074
229	-0.065
237	-0.057
247	-0.046
256	-0.037
264	-0.029
275	-0.018
287	-0.006
314	0.021
338	0.045
351	0.058
CURVE 13*	
293	0.000
573	0.504

T	$\Delta L/L_0$
CURVE 14*	
293	0.000
573	0.504
CURVE 15*	
293	0.000
573	0.532
CURVE 16*	
293	0.000
573	0.504
CURVE 17*	
50	-0.434
60	-0.409
72	-0.401
79	-0.389
82	-0.403
87	-0.387
106	-0.350
116	-0.339
153	-0.271
293	0.000
298	0.009
CURVE 18*	
84	-0.359
92	-0.351
98	-0.340
106	-0.335
110	-0.329
122	-0.318
131	-0.306
136	-0.297
145	-0.289
148	-0.286
155	-0.272
182	-0.222
208	-0.180
234	-0.127
272	-0.042
293	0.000
299	0.011

T	$\Delta L/L_0$
CURVE 19*	
99	-0.313
105	-0.308
110	-0.303
115	-0.296
122	-0.288
126	-0.283
131	-0.278
138	-0.269
152	-0.260
152	-0.255
156	-0.250
166	-0.240
176	-0.226
180	-0.216
194	-0.196
204	-0.184
214	-0.163
219	-0.151
234	-0.121
262	-0.067
275	-0.037
293	0.000
298	0.012
CURVE 20*	
298	0.010
374	0.126
472	0.304
572	0.482
671	0.633
772	0.798
784	0.808
CURVE 21*	
784	0.808
772	0.777
672	0.585
572	0.400
472	0.242
373	0.072
298	-0.033

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 346. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS TELLURIDES AND MIXTURES

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3*,‡	
25	-0.85
29	-1.18
34	-0.80
42	-0.22
53	1.16
63	2.23
75	3.65
89	4.39
90	4.69
99	4.88
101	5.17
104	5.13
105	5.42
112	5.69
118	6.03
121	5.93
127	6.24
128	6.53
131	6.53
131	6.24
138	6.80
143	7.10
148	7.10
154	7.65
155	7.55
157	7.65
169	7.75
171	7.83
176	7.96
178	7.96
187	8.24
194	8.24
196	8.41
204	8.55
208	8.45
212	8.51
212	8.64
221	8.71
231	8.71
232	8.89
243	8.89
246	8.89
250	8.77
257	8.89
267	8.89
270	8.89

T	α
CURVE 3 (cont.)*,‡	
277	8.98
286	8.85
288	9.05
300	9.04
302	9.04
306	9.06
319	9.19
324	9.09
335	9.28
336	9.22
CURVE 4*,‡	
293	12.05
309	12.11
336	12.21
370	12.35
389	12.34
417	12.42
440	12.47
463	12.47
491	12.61
520	12.83
550	12.60
575	12.60
594	12.92
614	12.83
641	13.04
657	13.23
669	13.00
678	13.22
683	13.82
693	15.76
696	17.62
698	19.09
700	19.71
709	19.97
724	19.95
757	19.77
CURVE 5*,‡	
293	13.70
313	13.82
333	13.94
356	14.10

T	α
CURVE 5 (cont.)*,‡	
372	14.24
407	14.61
426	14.66
449	14.64
474	15.07
495	15.00
514	15.37
547	15.35
561	15.68
582	15.63
611	15.98
626	15.95
637	16.24
647	16.41
657	16.54
665	16.89
678	18.22
683	20.17
685	20.71
696	20.73
709	20.70
750	20.76
CURVE 6*,‡	
315	13.49
325	13.71
340	13.60
353	13.87
373	14.19
386	14.06
404	14.21
423	14.21
439	14.31
453	14.35
469	14.41
482	14.37
501	14.70
513	14.98
543	15.42
558	15.79
563	16.25
580	16.95
591	17.65
607	18.93
610	19.50

T	α
CURVE 6 (cont.)*,‡	
626	21.63
627	22.42
639	37.01
645	44.40
651	23.44
683	22.22
696	22.25
732	22.29
766	22.36
CURVE 7*,‡	
305	14.72
322	14.89
333	14.78
356	15.01
368	14.81
379	14.99
395	14.85
412	15.01
427	15.05
438	15.14
460	15.20
474	15.27
491	15.12
502	15.24
513	15.35
525	15.35
530	15.49
551	15.44
564	15.62
568	15.91
582	16.28
589	16.71
595	17.20
600	17.84
601	18.43
604	21.13
611	24.50
621	35.43
629	38.13
633	22.18
639	21.19
661	21.10
700	21.19
731	21.37
757	21.29

T	α
CURVE 8*,‡	
293	11.3
312	11.3
340	11.0
368	10.3
395	11.6
428	11.6
460	11.9
488	12.1
520	12.7
549	14.7
571	15.7
584	15.9
599	14.8
609	12.3
614	10.7
616	8.3
625	-4.0
627	-13.4
630	-400.1
632	-35.8
630	5.2
630	8.8
630	13.9
649	37.6
651	27.7
666	24.7
667	30.3
673	23.6
680	23.6
692	21.6
698	23.2
714	22.7
720	23.6
745	24.2
CURVE 9*,‡	
737	24.8
659	25.0
652	25.3
635	42.6
619	-800.0
616	-400.1
611	-16.6
608	-11.8
603	-9.5

T	α
CURVE 9 (cont.)*,‡	
597	-6.2
590	-7.1
580	-2.9
568	-0.6
550	1.5
532	2.6
505	4.1
477	4.5
447	5.9
416	6.6
384	7.2
361	7.9
339	8.2
319	8.4
293	9.0
CURVE 10*,‡	
293	19.0
307	19.4
324	20.1
333	20.2
345	19.8
356	21.2
369	21.2
382	22.1
408	23.0
420	23.8
434	24.1
446	25.6
458	26.0
470	27.9
484	28.9
498	29.5
510	30.4
526	31.0
538	33.9
548	35.6
555	36.8
560	39.0
567	40.7
573	43.4
580	46.3
587	49.4
595	51.0
606	60.0

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS TELLURIDES AND MIXTURES (continued)

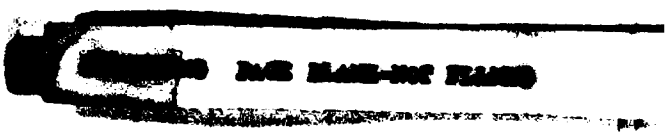
T	α
CURVE 10 (cont.)*,‡	
613	75.0
613	83.0
615	95.0
615	131.0
615	167.0
615	334.0
618	128.0
618	116.0
618	109.0
618	102.0
618	97.0
625	29.8
625	24.0
625	21.0
633	-28.4
633	40.0
633	37.5
CURVE 11*,‡	
728	24.5
714	24.3
641	27.5
625	41.9
625	-20.2
621	-27.3
618	47.1
617	70.0
618	173.0
616	222.0
616	266.0
612	432.0
612	336.0
611	389.0
611	42.4
608	55.0
602	148.0
602	124.0
602	96.0
602	36.4
599	34.0
597	31.9
591	30.6
589	29.1
572	28.5
563	26.6
550	26.3

T	α
CURVE 11 (cont.)*,‡	
537	23.2
525	22.1
512	21.1
487	20.7
466	20.0
442	19.2
420	18.7
400	18.5
382	18.1
354	17.7
CURVE 12*,‡	
26	2.40
31	3.03
36	3.42
45	4.78
56	5.59
62	6.14
72	7.03
86	7.38
88	7.59
93	7.81
101	8.04
102	7.87
108	8.25
112	8.01
117	8.49
119	8.33
124	8.72
128	8.79
137	9.08
138	8.90
146	9.11
151	9.31
155	9.12
163	9.28
166	9.42
173	9.72
181	9.70
186	9.76
191	9.76
200	9.96
210	10.02
220	10.00
229	10.08
237	10.08

T	α
CURVE 12 (cont.)*,‡	
247	10.14
256	10.06
264	9.96
275	10.03
287	10.09
314	10.09
338	10.07
351	10.11

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

6. CERAMICS



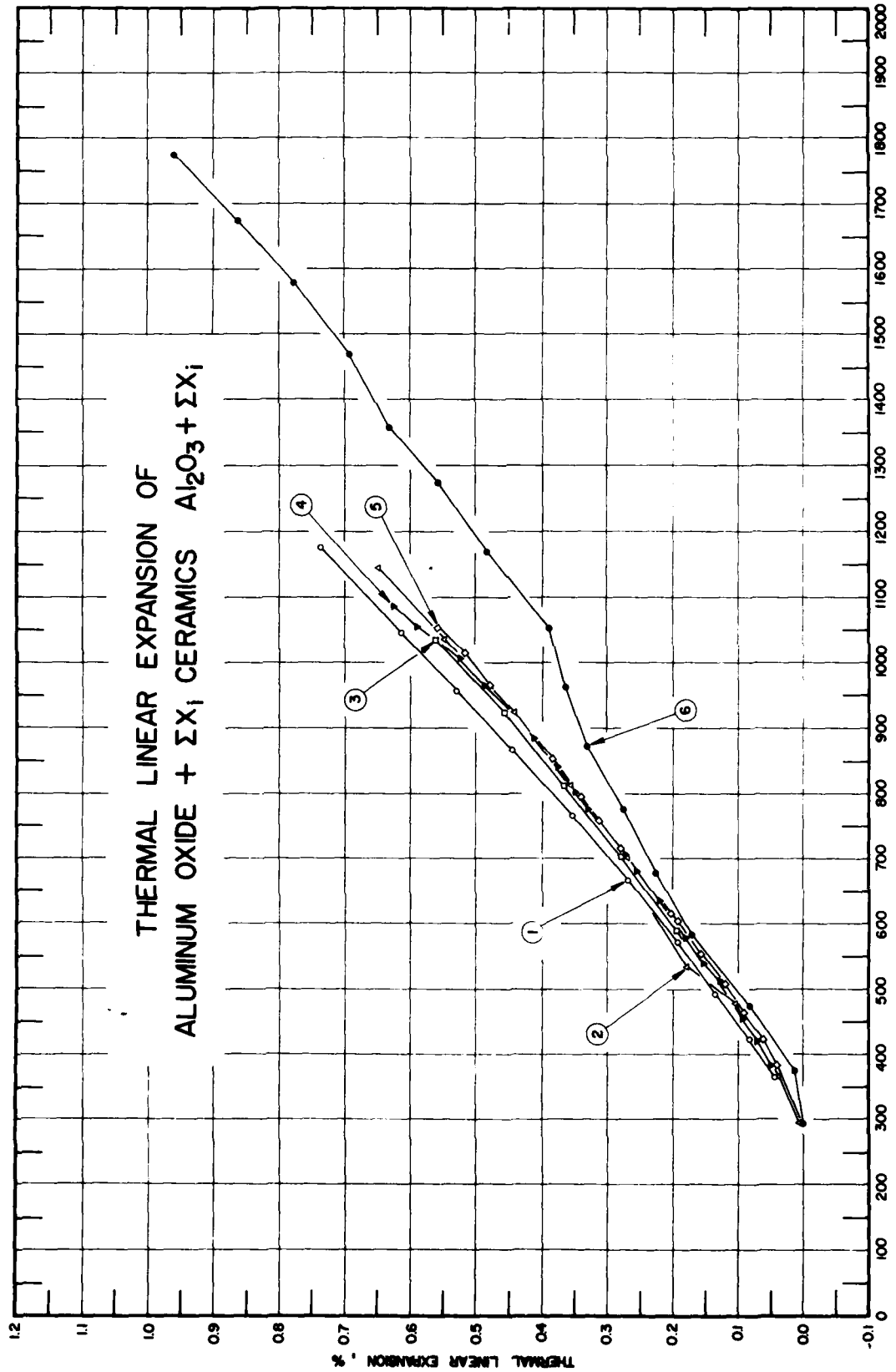

THERMAL LINEAR EXPANSION OF
ALUMINUM OXIDE + ΣXi CERAMICS Al2O3 + ΣXi
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1
2
3
4
5
6

FIGURE 347

SPECIFICATION TABLE 347. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE + ΣX_i CERAMICS $Al_2O_3 + \Sigma X_i$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	994	Warshaw, S.I. and Seider, R.	1967	L	366-1177		40.85 Al_2O_3, 29.58 Ajax P kaolin, 29.57 nepheline syenite; granular mixture pressed at 15,000 psi; to 100 gm mixture added 1 gm Carbowax binder; fired at 1250-1400 °; reported error 0.75%.
2	32	Filippi, F.J.	1963	L	297-1144	Specimen 1	97.6 Al_2O_3, International Pipe & Ceramics' GMcB351; 2 in. long.
3	32	Filippi, F.J.	1963	L	297-1034	Specimen 2	Similar to the above specimen.
4	32	Filippi, F.J.	1963	L	297-1086	AlSi Mag-96.0% Al_2O_3	American Lava's AlSi Mag-96.0% Al_2O_3; 2 in. long.
5	32	Filippi, F.J.	1963	L	297-1086	AlSi Mag-96.0% Al_2O_3	Similar to the above specimen; another run.
6	995	Gin'yar, E.A.	1969		293-1774	High alumina 50% Al_2O_3	52.18 Al_2O_3, 44.54 SiO_2, 1.09 TiO_2, 1.03 Fe_2O_3, 0.46 CaO, 0.34 alkalies, 0.27 MgO.

DATA TABLE 347. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE + ΣX_i CERAMICS $Al_2O_3 + \Sigma X_i$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
366	0.046
423	0.083
492	0.136
571	0.194
666	0.268
765	0.353
864	0.446
957	0.531
1045	0.615
1177	0.739
CURVE 2	
297	0.005
366	0.040
478	0.105
532	0.180
700	0.270
811	0.356
922	0.442
1033	0.548
1144	0.648
CURVE 3	
297	0.002*
370	0.040*
478	0.108*
589	0.196
701	0.278
811	0.367
923	0.457
1034	0.562
CURVE 4	
297	0.002*
384	0.049
421	0.071
455	0.094
512	0.129
540	0.153
579	0.181
634	0.221
680	0.253
703	0.273
776	0.329
801	0.348
840	0.375
884	0.412
924	0.440*
964	0.488
1007	0.525
1054	0.590
1086	0.625
CURVE 5	
297	0.002*
385	0.041
422	0.064
464	0.092
508	0.121
552	0.158
604	0.193
616	0.204
714	0.280
758	0.312
794	0.340
851	0.384
885	0.413*
925	0.446*
965	0.480
1013	0.518
1051	0.559
1086	0.625*
CURVE 6	
293	0.000
377	0.014
473	0.083
582	0.173
676	0.227
775	0.276
870	0.331
962	0.365
1052	0.389
1169	0.484
1273	0.558
1358	0.632
1470	0.692
1580	0.778
1674	0.864
1774	0.960

* Not shown in figure.

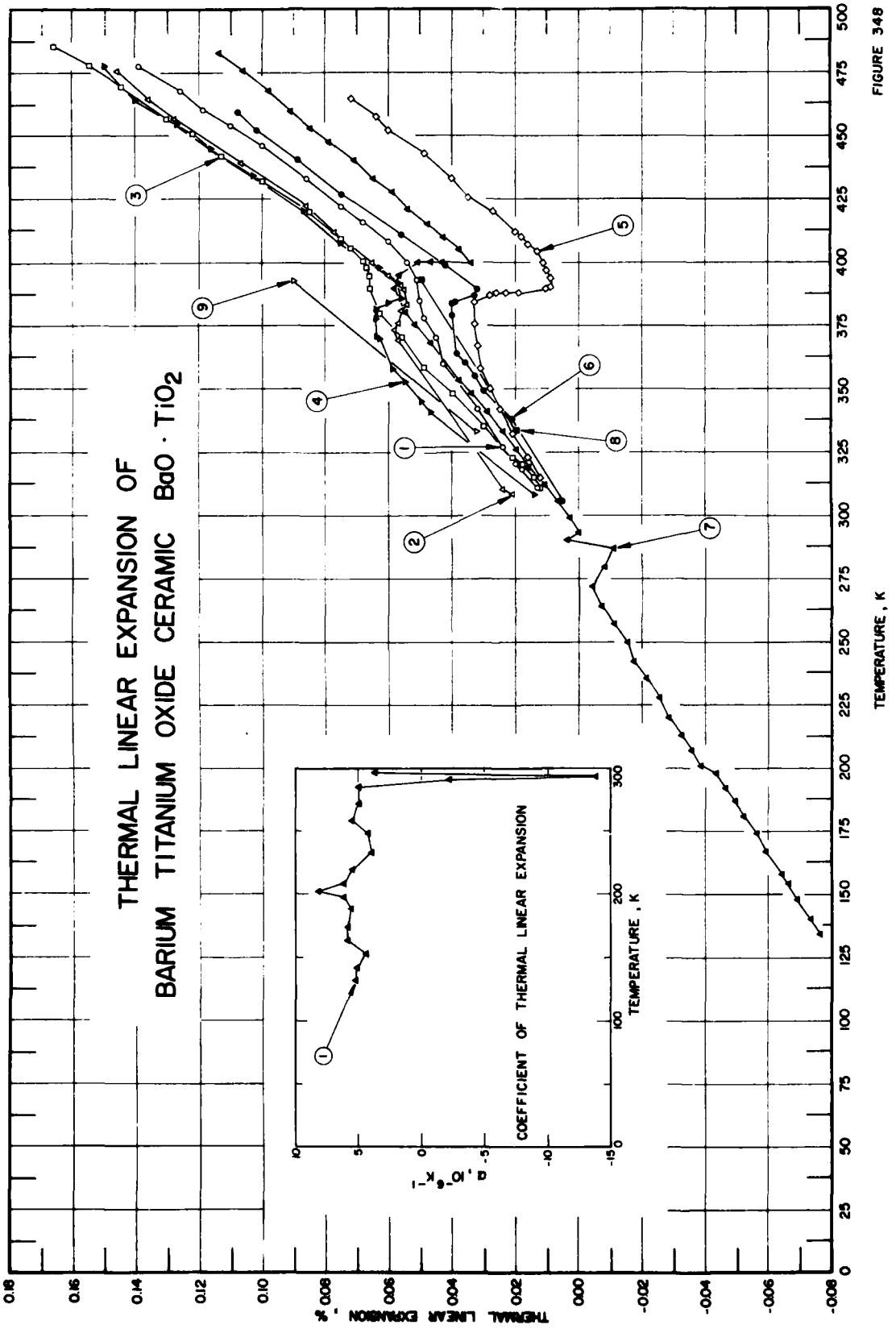

THERMAL LINEAR EXPANSION OF
BARIUM TITANIUM OXIDE CERAMIC BaO · TiO2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K

FIGURE 348

SPECIFICATION TABLE 348. THERMAL LINEAR EXPANSION OF BARIUM TITANIUM OXIDE CERAMIC $BaO \cdot TiO_2$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	989	Cook, W.R., Berlincourt, D.A., and Scholz, F.J.	1963	I	311-478	S	Expansion measured with increasing temperature on unpolarized specimen; zero-point correction is 0.010%.
2	989	Cook, W.R., et al.	1963	I	476-308	S	The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.022%.
3	989	Cook, W.R., et al.	1963	I	311-486	S_1	Expansion measured perpendicular to direction of electrical polarization with increasing temperature; zero-point correction is 0.008%.
4	989	Cook, W.R., et al.	1963	I	478-308	S_1	The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.023%.
5	989	Cook, W.R., et al.	1963	I	315-465	S_2	Expansion measured parallel to direction of electrical polarization with increasing temperature; zero-point correction is 0.008%.
6	989	Cook, W.R., et al.	1963	I	460-306	S_2	The above specimen; expansion measured with decreasing temperature.
7	990	Shirane, G. and Takeda, A.	1952	L	134-483		Specimen cylindrical form, 3 cm long, 4 mm diameter; prepared from high purity TiO_2 (99.2), $BaCO_3$ (99.6) by process of sintering at about 1673 K after preliminary calcination; zero-point correction is -0.004%.
8	837	Kimura, S. and Uchida, S.	1968	X	293-393	No. 6	Heat treatment 1370 C; 10 mm diameter, 0.3 mm width.
9	837	Kimura, S. and Uchida, S.	1968	X	293-393	No. 8	Heat to 1250 C and form ceramic; 10 mm diameter, 0.3 mm width.

DATA TABLE 348. THERMAL LINEAR EXPANSION OF BARIUM TITANIUM OXIDE CERAMIC $BaO \cdot TiO_2$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
311	0.013
318	0.018
320	0.020
327	0.024
342	0.032
360	0.043
370	0.045
378	0.049
385	0.050
393	0.051
400	0.054
408	0.060
416	0.068
422	0.075
433	0.086
446	0.100
454	0.110
461	0.119
468	0.126
478	0.139

CURVE 2

T	$\Delta L/L_0$
476	0.146
465	0.136
457	0.128
439	0.107
422	0.086
412	0.077
400	0.065
395	0.060
391	0.056
389	0.055
383	0.054
381	0.056
376	0.057
373	0.058
369	0.057
310	0.024
308	0.021

CURVE 3

T	$\Delta L/L_0$
311	0.012
315	0.014
320	0.018

CURVE 3 (cont.)

T	$\Delta L/L_0$
323	0.021
335	0.030
348	0.040
358	0.049
370	0.056
380	0.063
390	0.066
395	0.066
398	0.067
401	0.068
406	0.072
409	0.075
420	0.086
432	0.100
442	0.113
451	0.122
457	0.130
470	0.145
478	0.155
486	0.166

CURVE 4

T	$\Delta L/L_0$
478	0.150
46[illegible]	0.140
455	0.127
445	0.116
434	0.103
421	0.087
408	0.075
398	0.063
392	0.057
386	0.056
384	0.060
382	0.064
378	0.064
371	0.064
370	0.063
358	0.059
353	0.055
345	0.050
341	0.047
308	0.014

CURVE 5

T	$\Delta L/L_0$
315	0.012
323	0.016
332	0.021
342	0.025
350	0.028
358	0.031
367	0.032
376	0.033
384	0.033
387	0.028
388	0.026
388	0.023
388	0.019
390	0.010
391	0.009
394	0.009
397	0.010
400	0.011
404	0.013
407	0.016
410	0.018
412	0.020
420	0.027
426	0.035
433	0.040
443	0.049
452	0.060
457	0.064
465	0.072

CURVE 6

T	$\Delta L/L_0$
460	0.108
452	0.102
441	0.089
427	0.075
411	0.056
399	0.042
390	0.032
387	0.033
385	0.039
384	0.040
379	0.040
364	0.039
361	0.036
355	0.033

CURVE 6 (cont.)

T	$\Delta L/L_0$
349	0.030
338	0.021
306	0.005

CURVE 7

T	$\Delta L/L_0$
134	-0.076
141	-0.073
148	-0.069
154	-0.066
158	-0.064
167	-0.059
174	-0.056
181	-0.052
187	-0.049
192	-0.046
198	-0.043
201	-0.038
207	-0.035
213	-0.032
220	-0.028
228	-0.025
236	-0.021
242	-0.017
250	-0.015
257	-0.011
264	-0.007
272	-0.004
279	-0.008
287	-0.011
291	0.004
293	0.000
299	0.003
306	0.007
312	0.011
319	0.016
326	0.020
333	0.024
341	0.029
348	0.034
353	0.038
361	0.043*
368	0.047
375	0.052
381	0.055
390	0.058

CURVE 7 (cont.)

T	$\Delta L/L_0$
395	0.057
399	0.054*
400	0.051
400	0.047
400	0.043
399	0.034
405	0.038
410	0.043
315	0.048
421	0.054
427	0.059
433	0.065
440	0.071
447	0.079
453	0.085
460	0.091
468	0.098
476	0.106
483	0.114

CURVE 8

T	$\Delta L/L_0$
293	0.000
333	0.020
393	0.050

CURVE 9

T	$\Delta L/L_0$
293	0.000
333	0.032
393	0.090

* Not shown in figure.

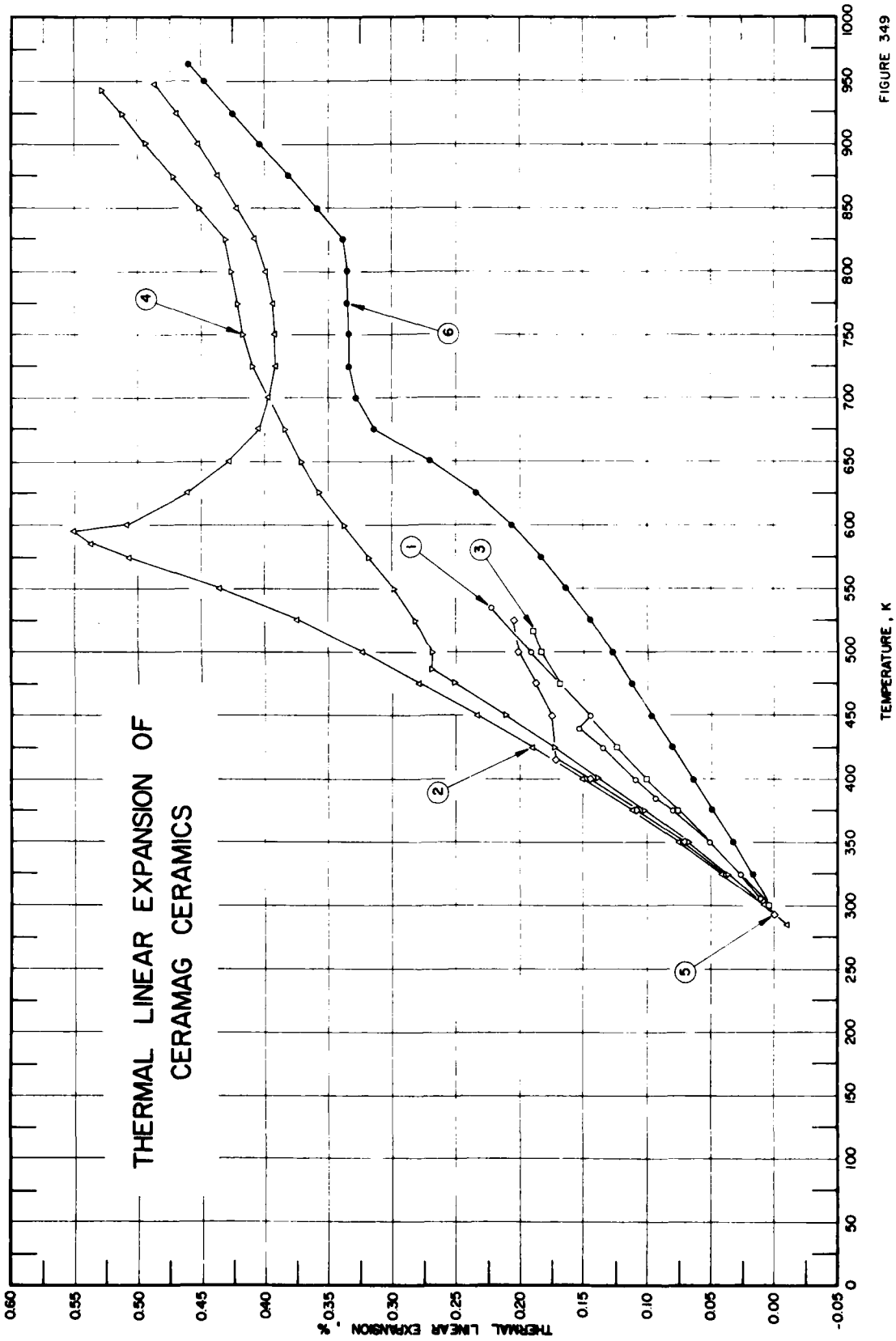

THERMAL LINEAR EXPANSION OF
CERAMAG CERAMICS
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1
2
3
4
5
6

FIGURE 349

SPECIFICATION TABLE 349. THERMAL LINEAR EXPANSION OF CERAMAG CERAMICS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	991	Buessem, W.R. and Dorf, A.	1957	L	306-535	Ceramag 7A	Specimen obtained from commercial source; Curie temperature 448 K.
2	991	Buessem, W.R. and Dorf, A.	1957	L	285-947	Ceramag 23B	Specimen obtained from commercial source; Curie temperature 593 K.
3	991	Buessem, W.R. and Dorf, A.	1957	L	300-516	Ceramag 9	Specimen obtained from commercial source; Curie temperature 483 K.
4	991	Buessem, W.R. and Dorf, A.	1957	L	300-943	Ceramag 27	Specimen obtained from commercial source; Curie temperature 497 K.
5	991	Buessem, W.R. and Dorf, A.	1957	L	293-525	Ceramag 2817	Specimen obtained from commercial source; Curie temperature 443 K.
6	991	Buessem, W.R. and Dorf, A.	1957	L	300-963	Ceramag 7441	Specimen obtained from commercial source; Curie temperature 663 K.

DATA TABLE 349. THERMAL LINEAR EXPANSION OF CERAMAG CERAMICS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
306	0.011
325	0.027
350	0.051
375	0.079
385	0.094
400	0.110
425	0.136
440	0.154
450	0.145
500	0.192
535	0.223
CURVE 2‡	
285	-0.010
300	0.008
325	0.041
350	0.075
375	0.112
400	0.150
425	0.191
450	0.234
475	0.279
500	0.324
525	0.375
550	0.437
575	0.508
585	0.538
595	0.551
600	0.510
625	0.461
650	0.429
675	0.407
700	0.398
725	0.392
750	0.393
775	0.394
800	0.400
825	0.409
850	0.423
875	0.438
900	0.453
925	0.470
947	0.487
CURVE 3‡	
300	0.006
325	0.028*
350	0.051*
375	0.077
400	0.101
425	0.124
450	0.146*
475	0.169
500	0.184
516	0.189
CURVE 4‡	
300	0.008*
325	0.037
350	0.068
375	0.102
401	0.139
425	0.173
450	0.211
476	0.252
486	0.270
500	0.270
525	0.282
550	0.299
575	0.319
600	0.338
626	0.358
650	0.372
675	0.385
700	0.398*
725	0.410
750	0.418
775	0.422
800	0.427
825	0.432
850	0.452
875	0.473
901	0.494
925	0.513
943	0.529
CURVE 5‡	
293	0.000
300	0.007*
325	0.039*
350	0.071
375	0.110
400	0.145
415	0.172
425	0.174*
450	0.175
475	0.188
500	0.202
525	0.204
CURVE 6‡	
300	0.004*
325	0.017
350	0.033
375	0.049
400	0.065
425	0.081
450	0.097
475	0.113
500	0.128
525	0.145
550	0.164
575	0.184
600	0.207
625	0.235
650	0.271
675	0.314
700	0.329
725	0.334
750	0.334
775	0.336
800	0.336
825	0.339
850	0.360
875	0.383
900	0.405
925	0.426
950	0.448
963	0.460

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 349. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CERAMAG CERAMICS

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

CURVE 1*,‡

T	α
306	7.33
325	7.90
350	8.46
375	9.08
385	9.69
400	9.74
425	9.86
440	10.05
450	9.01
500	9.06
535	9.06

CURVE 2*,‡

T	α
285	11.68
300	11.97
325	12.43
350	12.85
375	13.31
400	13.72
425	14.16
450	14.56
475	14.99
500	15.34
525	15.85
550	16.65
575	17.60
585	18.00
595	17.86
600	16.34
625	13.79
650	12.02
675	10.72
700	9.89
725	9.21
750	8.74
775	8.33
800	8.05
825	7.84
850	7.75
875	7.67
900	7.61
925	7.58
947	7.58

CURVE 3‡

T	α
300	7.18
325	7.85
350	8.37
375	8.85
400	9.00
425	9.01
450	9.01
475	9.01
500	8.68
516	8.33

CURVE 4‡

T	α
300	9.73
325	10.66
350	11.24
375	11.82
401	12.28
425	12.58
450	12.95
476	13.32
486	13.51
500	12.69
525	11.90
550	11.44
575	11.15
600	10.90
626	10.64
650	10.34
675	10.03
700	9.75
725	9.46
750	9.13
775	8.77
800	8.45
825	8.15
850	8.14
875	8.15
901	8.15
925	8.15
943	8.17

CURVE 5*,‡

T	α
293	9.97
300	10.16

CURVE 5 (cont.)*,‡

T	α
325	11.28
350	11.86
375	12.76
400	13.03
415	13.55
425	12.77
450	11.20
475	10.32
500	9.77
525	8.89

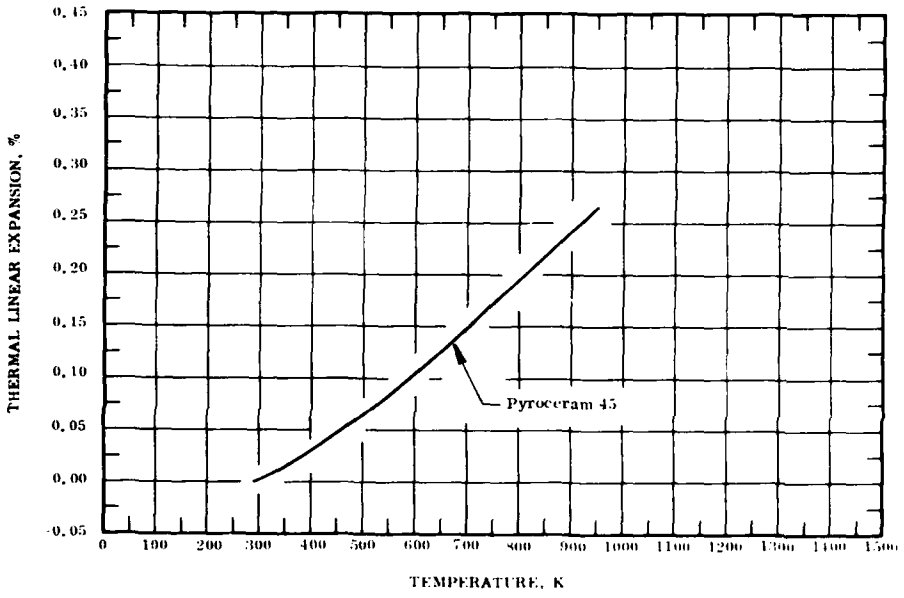
CURVE 6*,‡

T	α
300	4.32
325	4.88
350	5.36
375	5.61
400	5.74
425	5.86
450	5.94
475	5.98
500	6.01
525	6.09
550	6.22
575	6.35
600	6.59
625	6.90
650	7.39
675	8.00
700	7.89
725	7.57
750	7.18
775	6.86
800	6.53
825	6.30
850	6.38
875	6.49
900	6.59
925	6.65
950	6.73
963	6.78

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 350R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF PYROCERAM CERAMICS



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	2.2
350	0.015	2.7
400	0.029	3.2
450	0.045	3.5
500	0.064	3.8
550	0.084	4.1
600	0.105	4.3
650	0.127	4.5
700	0.150	4.6
750	0.174	4.7
800	0.196	4.8
850	0.219	4.8
900	0.242	4.9
950	0.264	5.0

REMARKS

The recommended values are based on the data for pyroceram 45 (Curves 2 to 5) and are considered accurate to within ±5%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.012 - 1.689 \times 10^{-4}\, T + 8.188 \times 10^{-7}\, T^2 - 3.532 \times 10^{-10}\, T^3$$

The tabulated values for the coefficient of thermal expansion are primarily derived by differentiating the above equation and are considered accurate to about ±5%.

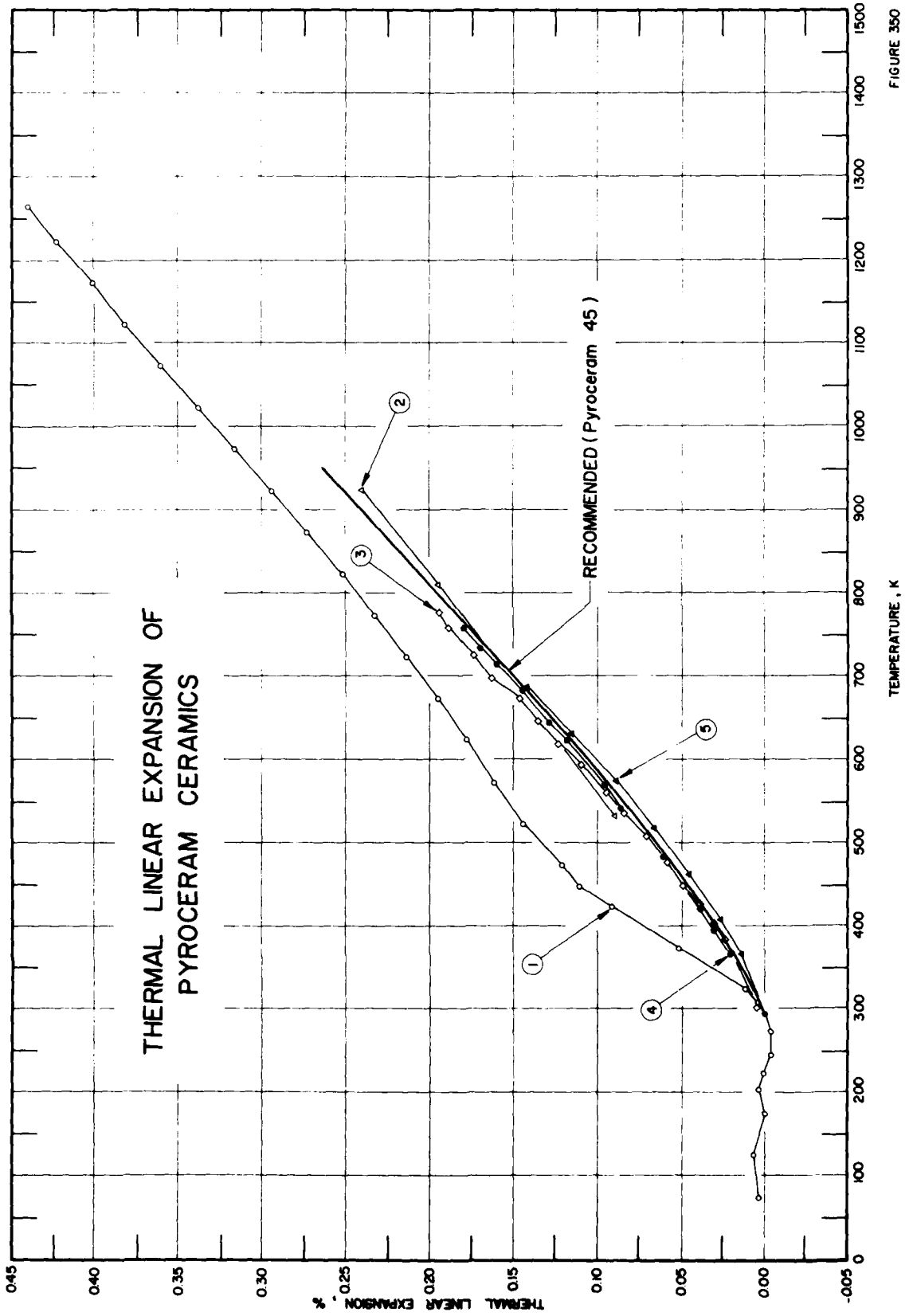

THERMAL LINEAR EXPANSION OF
PYROCERAM CERAMICS
RECOMMENDED (Pyroceram 45)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-.005
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1
2
3
4
5

FIGURE 350

SPECIFICATION TABLE 350. THERMAL LINEAR EXPANSION OF PYROCERAM CERAMICS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1052	Corning Glass Works	1958		73-1266	Pyroceram 9606	Hard, fine-grained crystalline material formed from special glasses; density 2.6 g cm^{-3}; zero-point correction is 0.004%.
2	993	Filippi, F.J.	1963	L	533-922	Monolithic adhesive; Pyroceram 45	Specimen dimension 0.25 x 0.30 x 2.0 in.
3	32	Filippi, F.J.	1963	L	300-775	Pyroceram 45	Cast adhesive, 2 in. long; specimen No. 1.
4	32	Filippi, F.J.	1963	L	300-758	Pyroceram 45	Similar to the above specimen; specimen No. 2.
5	32	Filippi, F.J.	1963	L	300-756	Pyroceram 45	Similar to the above specimen; specimen No. 3.

DATA TABLE 350. THERMAL LINEAR EXPANSION OF PYROCERAM CERAMICS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 1 (cont.)		CURVE 3		CURVE 4		CURVE 5	
73	0.003	723	0.214	300	0.005	300	0.005*	300	0.005*
123	0.007	773	0.233	383	0.024	367	0.021	366	0.014
173	0.000	823	0.252	402	0.031	394	0.031	408	0.027
203	0.003	873	0.274	427	0.039	420	0.039	461	0.046
223	0.001	923	0.294	449	0.049	448	0.050*	518	0.067
245	-0.004	973	0.317	477	0.059	481	0.061	574	0.089
273	-0.004	1023	0.338	509	0.072	503	0.070	630	0.116
293	0.000	1073	0.361	535	0.084	540	0.086	685	0.143
308	0.004	1123	0.382	560	0.095	570	0.096	740	0.170
323	0.012	1173	0.401	594	0.110	596	0.108*	756	0.179*
373	0.052	1223	0.423	619	0.124	621	0.118		
423	0.091	1266	0.440	646	0.136	644	0.129		
448	0.111			671	0.147	681	0.145		
473	0.121	CURVE 2‡		698	0.163	713	0.160		
523	0.144			725	0.175	733	0.170		
573	0.162	533	0.090	758	0.189	758	0.180		
623	0.178	810	0.195	775	0.196				
673	0.195	922	0.241						

DATA TABLE 350. COEFFICIENT OF THERMAL LINEAR EXPANSION OF PYROCERAM CERAMICS

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α
CURVE 1*		CURVE 1 (cont.)*	
281	1.18	723	3.97
293	1.89	773	4.02
323	4.00	823	4.11
349	6.03	873	4.18
373	7.34	923	4.24
381	7.61	973	4.32
403	7.61	1023	4.41
423	6.95	1073	4.48
455	5.15	1123	4.55
473	4.35	1173	4.62
484	3.84	1223	4.69
492	3.70	1273	4.77
505	3.63		
523	3.63	CURVE 2*,‡	
573	3.73		
623	3.80	533	3.51
673	3.90	810	4.03
		922	4.23

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

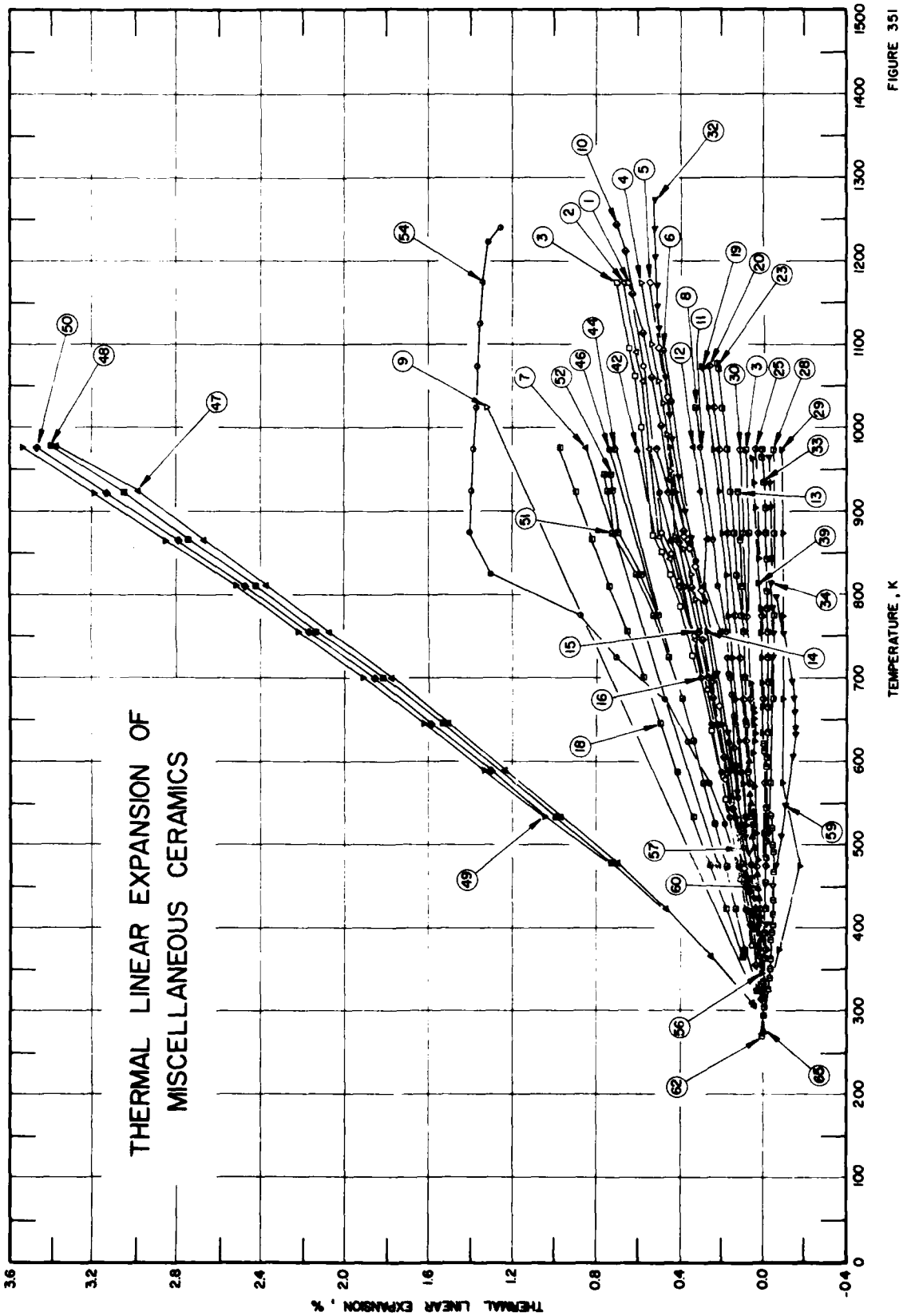

THERMAL LINEAR EXPANSION OF
MISCELLANEOUS CERAMICS
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 351

SPECIFICATION TABLE 351. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERAMICS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	994	Warshaw, S.I. and Seider, R.	1967	L	378-1173		34.25 Ajax P kaolin, 34.25 nepheline syenite, 31.5 SiO_2; mixture with grain size 3 μ diameter pressed at 15,000 psi; 100 gm specimen added 1 gm Carbowax binder and fired at 1250-1400 C; reported error 0.75%.
2	994	Warshaw, S.I. and Seider, R.	1967	L	378-1173		Similar to the above specimen except grain size 7 μ diameter.
3	994	Warshaw, S.I. and Seider, R.	1967	L	378-1173		Similar to the above specimen except grain size 25 μ diameter.
4	994	Warshaw, S.I. and Seider, R.	1967	L	478-1173		Similar to the above specimen except grain size 50 μ diameter.
5	994	Warshaw, S.I. and Seider, R.	1967	L	378-1173		Similar to the above specimen except grain size 80 μ diameter.
6	994	Warshaw, S.I. and Seider, R.	1967	L	378-1173		Similar to the above specimen except grain size 150 μ diameter.
7	999	Nosova, Z.A. and Lyubina, T.M.	1968		473,973	Magnesia foamed ceramic	Porous article 200 x 120 x 50 mm, apparent density of 0.5-2.0 g cm^{-3} using foam method and water suspensions; involved the use of magnesium oxide, 99.3-99.7 MgO; material subjected to double firing at 1200 C and 1600-1650 C; hydration is 4.5-4.7%.
8	1000	Deadmore, D.L.	1950	I	293, 1023	A Zircon body	25.0 Zircon; 25.0 Keystone Feldspar; 25.0 Tennessee #5 Ball Clay; 25.0 George Kaolin; column of 1 in. x 1 in. x 5 in.; purified ball clays added to remaining constituents in a ball mill, and milled for 5.5 hr; milled slip dewatered in plaster absorption bats to proper extrusion consistency; bar extruded, air dried, burned in a gas-fired kiln to cone 12 in 32 hr, after a soaking period of 4 hr the kiln allowed to cool to room temperature.
9	1000	Deadmore, D.L.	1950	I	293, 1023	A Zircon body	Similar to the above specimen; heated in electric furnace; then quenched from 593 C in 17 C water for 5 min.
10	1001	Auda, D.	1962	L	293-1244		97.0 Al_2O_3 (Alcoa A-14); 1.5 MnO added as MnO_2, reagent; 1.5 TiO_2 reagent; honeycomb sandwich specimen; sandwich core material cast by a plaster mold, panel skins cast on flat plaster slabs, cores and skins assembled by painting the mating surfaces with a slip No. 58 ground with 1% of methyl-cellulose (4000 cps); pieces pressed together, dried at 120 F, panel fired in a silicon carbide resistance furnace to 2550 F.
11	181	Smoke, E.J., Rooda, J., Sirkis, M.D., Holsberg, P.J., Molony, D.A., and Choa, C.	1960	L	366-977		62.5 Zircon, 12.5 #4 ball clay, 25.0 magnesium zirconium silicate; fired at 1811 K, 0.00% water absorption; bulk density 3.62 gm/cm^3.
12	181	Smoke, E.J., et al.	1960	L	366-977		62.5 Zircon, 12.5 #4 ball clay, 25.0 calcium zirconium silicate; fired at 1811 K, 0.01% water absorption; bulk density 3.50 gm/cm^3.
13	181	Smoke, E.J., et al.	1960	L	366-922		15.4 lithium carbonate, 4.1 alumina, 38.9 silica, 2.6 titania, 39.0 E.P.K. clay; fritted at 1733 K, fired at 1567 K, 0.28% water absorption; bulk density 2.22 gm/cm^3.
14	181	Smoke, E.J., et al.	1960	L	366-977		35.0 feldspar (A-3), 25.0 flint, 28.0 E.P.K. clay, 10.0 #4 ball clay, 2.0 Whiting, $CaCO_3$; fired at 1483 K, 0.34% water absorption; bulk density 2.40 gm/cm^3.
15	181	Smoke, E.J., et al.	1960	L	366-977		90.0 alumina (A-14), 6.0 talc Montana No. 1736, ball clay (Victoria); sintered at 1756 K, fired at 1833 K, 0.00% water absorption; bulk density 3.60 gm/cm^3.
16	181	Smoke, E.Y., et al.	1960	L	366-977		25.5 magnesia, 53.5 alumina, 21.0 E.P.K. clay; fired at 1811 K, 0.00% water absorption; bulk density 3.08 gm/cm^3.

SPECIFICATION TABLE 351. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERAMICS (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
17*	181	Smoke, E.Y., Rooda, J., Sirkis, M.D., Holsberg, P.J., Molony, D.A., and Choa, C.	1960	L	366-977		21.7 magnesia, 37.8 alumina, 40.5 E.P.K. clay; fired at 1728 K, 0.00% water absorption; bulk density 2.87 gm/cm^3.
18	181	Smoke, E.Y., et al.	1960	L	366-977		77.0 talc, 11.5 barium carbonate, 11.5 E.P.K. clay; fired at 1561 K, 0.00% water absorption; bulk density 2.83 gm/cm^3.
19	997	Hummel, F.A. and Henry, E.C.	1946		293-1077	Zircon-beryl bodies 9A	Body composed of 95% 200-mesh milled commercial grade Zircon obtained from Titanium Alloy Manufacturing Co., bonded by 5% finely ground beryl obtained from Consolidated Feldspar Corp.; at 800 C fired at 1370 C for 2 hr.
20	997	Hummel, F.A. and Henry, E.C.	1946		293-1074	Zircon-beryl bodies 9B	Similar to the above specimen; 90% milled Zircon, 5% beryl.
21*	997	Hummel, F.A. and Henry, E.C.	1946		293-1073	Zircon-beryl bodies 9C	Similar to the above specimen; 85% milled Zircon, 15% beryl.
22	997	Hummel, F.A. and Henry, E.C.	1946		293-1081	Zircon beryl bodies 9D	Similar to the above specimen; 80% milled Zircon, 20% beryl.
23	997	Hummel, F.A. and Henry, E.C.	1946		293-1077	Zircon-beryl bodies 9E	Similar to the above specimen; 75% milled Zircon, 25% beryl.
24*	997	Hummel, F.A. and Henry, E.C.	1946		297-1084	Zircon-beryl bodies 9F	Similar to the above specimen; 70% milled Zircon, 30% beryl.
25	998	Smoke, E.J., Arlett, R.H., Phillips, C.J., and Halpern, A.S.	1958	L	373-973	QC6F1	Magnesium lithium alumino-silicate body, 61.0 frit, 39.0 clay, oxide composition of frit, 80.0 SiO_2, 12.0 Li_2O, 8.0 Al_2O_3; firing
26*	998	Smoke, E.J., et al.	1958	L	373-973	MQC6F1	Magnesium lithium alumino-silicate body, 61.0 frit, 39.0 clay, oxide composition of frit, 80.0 SiO_2, 11.5 Li_2O, 8.0 Al_2O_3, 0.5 MgO; firing temperature 2020 F; heating rate 2 to 3 deg per min.
27*	998	Smoke, E.J., et al.	1958	L	373-973	MQC6F2	Similar to the above specimen except oxide composition 80.0 SiO_2, 11.0 Li_2O, 8.0 Al_2O_3, 1.0 MgO.
28	998	Smoke, E.J., et al.	1958	L	373-973	MQC6F3	Similar to the above specimen except oxide composition 80.0 SiO_2, 9.0 Li_2O, 8.0 Al_2O_3, 3.0 MgO.
29	998	Smoke, E.J., et al.	1958	L	373-973	MQC6F4	Similar to the above specimen except oxide composition 80.0 SiO_2, 8.0 Al_2O_3, 7.0 Li_2O, 5.0 MgO.
30	998	Smoke, E.J., et al.	1958	L	373-973	MQC6F5	Similar to the above specimen except oxide composition 80.0 SiO_2, 8.0 Al_2O_3, 7.0 MgO, 5.0 Li_2O.
31	998	Smoke, E.J., et al.	1958	L	373-973	MQC6F6	Similar to the above specimen except oxide composition 80.0 SiO_2, 9.0 MgO, 8.0 Al_2O_3, 3.0 Li_2O.
32	1002	Tinklepaugh, J.R., Goss, B.R., Hoskyns, W.R., Connor, J.H., and Button, D.D.	1960	L	373-1273	Body 715	50.0 calcined kaolin, 30.0 flint, 20.0 F-4 feldspar; specimen surface ground to a length of 4.0 in.

* Not shown in figure.

SPECIFICATION TABLE 351. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERAMICS (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
33	1003	Smoke, E.J., Ilyn, A.V., and Eichbaum, B.R.	1955	L	303-973	AL14	Aluminum titanate-petalite body; 60.0 petalite, 40.0 $Al_2O_3 \cdot TiO_2$; aluminum titanate fired to 1810.9 K in a large clay crucible and passed through a micropulverizer then added to petalite; heating rate 2 C to 3 C per min; temperature and expansion recorded every 15 min.
34	1003	Smoke, E.J., et al.	1955	L	303-973	AL15	60.0 petalite, 40.0 $Al_2O_3 \cdot TiO_2$; aluminum titanate prepared as tile, after firing, being crushed and ground to 200 mesh; similar to the above specimen.
35*	1003	Smoke, E.J., et al.	1955	L	303-973	AL18	50.0 petalite, 40.0 $Al_2O_3 \cdot TiO_2$, 10 E.P.K. clay; aluminum titanate prepared as tile, after firing, being crushed and ground to 200 mesh; similar to the above specimen.
36*	1003	Smoke, E.J., et al.	1955	L	303-971	AL20	40.0 petalite, 40.0 $Al_2O_3 \cdot TiO_2$, 20 E.P.K. clay; similar to the above specimen.
37*	1003	Smoke, E.J., et al.	1955	L	303-971	AL21	45.0 petalite, 30.0 $Al_2O_3 \cdot TiO_2$, 7.5 E.P.K. clay, 7.5 feldspar (Buckingham); similar to the above specimen.
38	1003	Smoke, E.J., et al.	1955	L	323-973	SQ20A Petalite-Frit-Clay bodies	60.0 petalite, 30.0 QC6 frit, 10.0 E.P.K. clay; matured at a high temperature to 0.00% moisture absorption, electrical properties in the grade L-3 range, transverse strength 6000 psi.
39	1003	Smoke, E.J., et al.	1955	L	323-973	SQ20	60.0 petalite, 30.0 QC6 frit, 10.0 Victoria ball clay; similar to the above specimen.
40*	1003	Smoke, E.J., et al.	1955	L	298,973	T2	80.0 talc (Sierra Hi-grade), 10.0 $BaCO_3$, 10.0 E.P.K. clay; crystalline phase, Enstatite; batches prepared by the refined dry mixing process, specimen fabricated by de-airing hydraulic extrusion process and fired in an open gas furnace in 5 hr plus 1 hr soaking period; heating rate 2-3 C per min.
41*	1003	Smoke, E.J., et al.	1955	L	298,973	T2.1	60.0 talc (Sierra Hi-grade), 20.0 Wollastonite, 10.0 $BaCO_3$, 10.0 E.P.K. clay; principal crystalline phase is diopside ($Ca \cdot Mg(SiO_3)_2$); similar to the above specimen.
42	1003	Smoke, E.J., et al.	1955	L	298,973	T2.2	40.0 talc (Sierra Hi-grade), 40.0 Wollastonite, 10.0 $BaCO_3$, 10.0 E.P.K. clay; principal crystalline phase is diopside; similar to the above specimen.
43*	1003	Smoke, E.J., et al.	1955	L	298,973	T2.3	60.0 Wollastonite, 20.0 talc (Sierra Hi-grade), 10.0 $BaCO_3$, 10.0 E.P.K. clay; similar to the above specimen.
44	1003	Smoke, E.J., et al.	1955	L	298,973	Body No. 5	40.0 SiO_2, 30.0 MgO, 30.0 BaO; specimen 4 in. long; prepared by the refined dry mixing process; heating rate 2-3 C per min.
45	1003	Smoke, E.J., et al.	1955	L	298,973	Body No. 5A	Batch composition 58.0 talc, 33.7 $BaCO_3$, 8.3 MgO; similar to the above specimen.
46	1003	Smoke, E.J., et al.	1955	L	298,973	Body No. 13A	Batch composition 54.6 $BaCO_3$, 31.6 talc, 13.8 MgO; similar to the above specimen.
47	1004	Smoke, E.J., Rooda, J., Molony, D.A., Kenner, B., Pecina, R., and Chao, C.	1962		306-978	T2	Base composition 62.5 zircon, 25.0 calcium zirconium silicate, 12.5 #4 ball clay, 2.0 TiO_2.
48	1004	Smoke, E.J., et al.	1963		306-978	T5	Similar to the above specimen except 5.0 TiO_2.
49	1004	Smoke, E.J., et al.	1963		306-978	BT5	Similar to the above specimen except 5 $BaTiO_3$ added.
50	1004	Smoke, E.J., et al.	1963		306-978	BT10	Similar to the above specimen except 10 $BaTiO_3$.

* Not shown in figure.

SPECIFICATION TABLE 351. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERAMICS (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
51	1005	Kawamura, S., Nishimura, T., Maeda, T., Ito, A., Asano, K., Mizuta, H., and Kumazawa, S.	1967	L	323-943	H	79.79 SiO_2, 14.53 Al_2O_3, 0.19 MgO, 0.16 CaO, 0.14 K_2O, 0.12 TiO_2, 0.11 Fe_2O_3, 0.10 Na_2O; heating rate 220 C/hr.
52	1005	Kawamura, S., et al.	1967	L	323-943	O	71.56 SiO_2, 20.54 Al_2O_3, 0.24 CaO, 0.22 TiO_2, 0.20 MgO, 0.18 Fe_2O_3, 0.09 K_2O, 0.08 Na_2O; heating rate 220 C/hr.
53*	1005	Kawamura, S., et al.	1967	L	323-943	Y	72.22 SiO_2, 20.21 Al_2O_3, 0.24 TiO_2, 0.22 Fe_2O_3, 0.20 CaO, 0.12 MgO, 0.09 K_2O, 0.08 Na_2O; heating rate 220 C/hr.
54	1006	Takagi, H. and Hayashi, H.	1967	L	293-1241	Izumiyama pottery stone Raw material	76.48 SiO_2, 14.00 Al_2O_3, 3.06 MnO, 2.71 K_2O, 1.47 Fe_2O_3, 0.36 CaO, 0.15 MgO, 0.11 Na_2O; heating rate 4 C/min.
55*	1006	Takagi, H. and Hayashi, H.	1967	L	293-1231	Izumiyama pottery stone Raw material D-3	78.20 SiO_2, 13.81 Al_2O_3, 2.65 K_2O, 0.40 Fe_2O_3, 0.13 MgO, 0.08 Na_2O, 0.08 CaO; heating rate 4 C/min.
56	989	Cook, W.R., Berlincourt, D.A., and Scholz, F.J.	1963	I	324-693	$Pb(Ti_{.48}Zr_{.52})O_3$	1.0% Nb_2O_5 added to $Pb(Ti_{0.48} + Zr_{0.52})O_3$ composition; unpolarized specimen; expansion measured with increasing temperature.
57	989	Cook, W.R., et al.	1963	I	317-723	$Pb(Ti_{.48}Zr_{.52})O_3$ S_1	Similar to the above specimen except electrically polarized; expansion measured perpendicular to polarization with increasing temperature.
58*	989	Cook, W.R., et al.	1963	I	293-574	$Pb(Ti_{.48}Zr_{.52})O_3$ S_1	Similar to the above specimen; expansion measured after heating specimen to 523 K, then cooling; expansion measured with increasing temperature.
59	989	Cook, W.R., et al.	1963	I	304-823	$Pb(Ti_{.48}Zr_{.52})O_3$ S_3	Similar to the above specimen; expansion measured parallel to direction of polarization.
60	989	Cook, W.R., et al.	1963	I	328-577	$Pb(Ti_{.48}Zr_{.52})O_3$ S_3	Similar to the above specimen; expansion measured with increasing temperature after heating at 523 K.
61*	1008	Smoke, E.J., Phillips, C.J., Kim, Y.S., Ulrich, D.R., Kastenbein, E.L., Schneider, F., Whelan, P., and Breen, C.	1960	I	273-628	GQC6F3	Frit composition 77.0 SiO_2, 12.0 Li_2O, 8.0 Al_2O_3, 3.0 GeO_2; containing beta-spodumene crystalline phase made by devitrification of a fabricated frit; fritting temperature 1744.2 K; firing temperature 1522.05 K; moisture absorption 0.29%.
62	1008	Smoke, E.J., et al.	1960	I	269-633	GQC6F2	79.0 SiO_2, 12.0 Li_2O, 8.0 Al_2O_3, 1.0 GeO_2 (frit composition); similar to the above specimen; fritting temperature 1788.72 K; firing temperature 1577.6 K; moisture absorption 0.21%.
63*	1008	Smoke, E.J., et al.	1960	I	269-591	GQC6F1	79.5 SiO_2, 12.0 Li_2O, 8.0 Al_2O_3, 0.5 GeO_2 (frit composition); similar to the above specimen.
64*	1008	Smoke, E.J., et al.	1960	I	273-636	BQC6F5	75.0 SiO_2, 12.0 Li_2O, 8.0 Al_2O_3, 5.0 B_2O_3 (frit composition); fritting temperature 1638.7 K; similar to the above conditions.
65	1008	Smoke, E.J., et al.	1960	I	273-650	QC6F1	Composition 61% frit, 39% clay (E.P.K.); (frit composition) 80.0 SiO_2, 12.0 Li_2O, 8.0 Al_2O_3; fritting temperature 1733.16 K; bulk density 2.24 g/cc.
66*	1008	Smoke, E.J., et al.	1960	I	269-457	TQC6F9	50 SiO_2, 30 TiO_2, 12.0 Li_2O, 8 Al_2O_3 (frit composition); containing beta-spodumene crystalline phase made by devitrification of a fabricated frit; fritting temperature 1666.5 K; bulk density 2.48 g/cc.

* Not shown in figure.

SPECIFICATION TABLE 351. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERAMICS (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
67*	1007	Stolypin, Y.E. and Isupov, V.A.	1968	D	293-480	Polarized Ceramic	36.08 $PbTiO_3$, 25.406 $PbZrO_3$, 28.512 $PbMg_{0.5}W_{0.5}O_3$ [(1-x)(0.6 $PbTiO_3$ + 0.4 $PbMg_{0.5}W_{0.5}O_3$ + x $PbZrO_3$), x = 0.34]; rod specimen 18 mm long with rectangular cross section, polarized in an electric field along length during cooling start from Curie temperature 120 C; polarization field 11 kv·cm^{-1}; zero-point correction is -0.242%.
68*	1007	Stolypin, Y.E. and Isupov, V.A.	1968	D	293-472	Polarized Ceramic	Similar to the above specimen except x = 0.28, composition 38.363 $PbTiO_3$, 31.319 $PbZrO_3$, 30.316 $PbMg_{0.5}W_{0.5}O_3$; Curie temperature 121 C; polarization field 11 kv·cm^{-1}; zero-point correction is -0.208%.
69*	1007	Stolypin, Y.E. and Isupov, V.A.	1968	D	293-505	Polarized Ceramic	The above specimen; polarization field 8 kv·cm^{-1}; zero-point correction is -0.192%.
70*	1007	Stolypin, Y.E. and Isupov, V.A.	1968	D	299-508	Polarized Ceramic	The above specimen; polarization field 0 kv·cm^{-1}; zero-point correction is -0.176%.
71*	1007	Stolypin, Y.E. and Isupov, V.A.	1968	D	296-502	Polarized Ceramic	Similar to the above specimen except x = 0.30; composition 39.398 $PbTiO_3$, 31.279 $PbMg_{0.5}W_{0.5}O_3$, 29.321 $PbZrO_3$; polarization field 15 kv cm^{-1}; Curie temperature 127 C; zero-point correction is -0.120%.
72*	1007	Stolypin, Y.E. and Isupov, V.A.	1968	D	293-499	Polarized Ceramic	The above specimen; polarization field 11 kv·cm^{-1}; zero-point correction is -0.114%.
73*	1007	Stolypin, Y.E. and Isupov, V.A.	1968	D	293-496	Polarized Ceramic	The above specimen; polarization field 0 kv·cm^{-1}; zero-point correction is -0.088%.
74*	992	Forlano, R.J.	1962	I	300-758	UI-117	27.5 SiO_2, 16.5 Na_2O, 13.1 Al_2O_3, 11.2 ZnO, 5.5 CaO, 5.2 K_2O, 5.1 Na_2SiF_6, 5.0 BaO, 4.1 B_2O_3, 4.0 P_2O_5, 2.7 V_2O_5; expansion measured with temperature increasing 5 K/min; zero-point correction is 0.007%.
75*	992	Forlano, R.J.	1962	I	300-723	UI-1058	63.5 PbO, 32.6 SiO_2, 3.9 Na_2O; similar to the above specimen; zero-point correction is 0.005%.
76*	992	Forlano, R.J.	1962	I	300-853	UI-1064	52.5 SiO_2, 35.9 FeO, 11.6 Na_2O; similar to the above specimen.
77*	992	Forlano, R.J.	1962	I	300-807	UI-1067	57.0 B_2O_3, 38.0 SiO_2, 5.0 Na_2O; similar to the above specimen; zero-point correction is 0.004%.
78*	992	Forlano, R.J.	1962	I	300-763	UI-1163	27.2 SiO_2, 16.3 Na_2O, 13.2 Al_2O_3, 11.0 ZnO, 6.0 BaO, 5.4 CaO, 5.1 K_2O, 5.0 Na_2SiF_6, 4.0 B_2O_3, 4.0 P_2O_5, 3.0 V_2O_5; 20.0 Au added; similar to the above specimen; zero-point correction is 0.008%.
79*	992	Forlano, R.J.	1962	I	300-894	UI-1201	49.4 $PbSiO_5$, 15.5 Na_2O, 15.0 Al_2O_3, 11.1 TiO_2, 9.0 SiO_2; similar to the above specimen; zero-point correction is 0.007%.
80*	993	Filippi, F.J.	1963	L	533-922	Monolithic adhesive, Pycerad 500	Specimen dimension, 0.250 x 0.300 x 2.0 in.
81*	993	Filippi, F.J.	1963	L	533-922	Monolithic adhesive, Interpace	Specimen dimension, 0.250 x 0.300 x 2.0 in.
82*	32	Filippi, F.J.	1963	L	398-1093	Pycerad 500	Sintered adhesive, 2 in. long.
83*	32	Filippi, F.J.	1963	L	302-998	Interpace	Cast adhesive, 2 in. long, specimen No. 1.
84*	32	Filippi, F.J.	1963	L	302-822	Interpace	Similar to the above specimen; specimen No. 2.

* Not shown in figure.

SPECIFICATION TABLE 351. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERAMICS (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
85*	996	Kallup, C., Sklarew, S., and Castner, S.V.	1964		364-1763	Thermarg ZSF-124	89.7 ZrO_2, 9.0 H_2SiF_6, 1.3 $NH_4H_2PO_4$; 57% of ZrO_2 30 mesh, remainder 325 mesh; specimen air dried.
86*	996	Kallup, C., et al.	1964		364-1755	Thermarg ZSF-124	Similar to the above specimen except cured at 505 K.
87*	996	Kallup, C., et al.	1964		477-1752	Thermarg ZSF-124	Similar to the above specimen except fired at 1755 K.
88*	988	Pryslak, N.E.	1955		307-1002	Alsimag 243	No details given; zero-point correction is 0.014%.
89*	991	Buessem, W.R. and Dorf, A.	1957	L	300-1174	Ceramagnetic A	Specimen obtained from commercial source; Curie temperature 733 K.

* Not shown in figure.

DATA TABLE 351. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERAMICS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
378	0.056
466	0.110
579	0.194
685	0.276
750	0.336
817	0.406
849	0.447
873	0.493
1074	0.582
1173	0.653

CURVE 2

T	$\Delta L/L_0$
378	0.057*
464	0.109*
580	0.194*
686	0.275*
747	0.338
809	0.407
843	0.453
869	0.503
974	0.554
1056	0.589
1090	0.612
1173	0.674

CURVE 3

T	$\Delta L/L_0$
378	0.060*
460	0.112
554	0.187
636	0.257
727	0.348
786	0.402
823	0.450
851	0.491
871	0.531
1000	0.593
1062	0.620
1096	0.647
1173	0.703

CURVE 4

T	$\Delta L/L_0$
478	0.105
585	0.183

CURVE 4 (cont.)

T	$\Delta L/L_0$
694	0.253
793	0.328
824	0.354
854	0.384
869	0.424
948	0.449
990	0.467
1029	0.484
1057	0.509
1100	0.543
1173	0.595

CURVE 5

T	$\Delta L/L_0$
378	0.042*
471	0.095
665	0.220
804	0.304
833	0.331
855	0.361
869	0.388
1037	0.467
1096	0.510
1173	0.556

CURVE 6

T	$\Delta L/L_0$
378	0.040
476	0.092*
622	0.177
791	0.282
841	0.326
862	0.357
871	0.379*
1033	0.452
1094	0.488
1173	0.544*

CURVE 7

T	$\Delta L/L_0$
473	0.225
973	0.850

CURVE 8

T	$\Delta L/L_0$
293	0.000
1023	0.328

CURVE 9

T	$\Delta L/L_0$
293	0.000*
1023	1.321

CURVE 10

T	$\Delta L/L_0$
293	0.000*
314	0.013*
357	0.036*
404	0.062
479	0.108*
543	0.156
604	0.197
676	0.246
746	0.301
810	0.346
877	0.397
941	0.450
1002	0.496
1062	0.542
1113	0.587
1162	0.633
1212	0.668
1244	0.706

CURVE 11

T	$\Delta L/L_0$
366	0.019
422	0.039
477	0.063
533	0.087
588	0.112
644	0.138
700	0.163
755	0.192
810	0.226
866	0.247
922	0.277
977	0.309

CURVE 12

T	$\Delta L/L_0$
366	0.022*
422	0.046*
477	0.073*
533	0.098*
588	0.130*

CURVE 12 (cont.)

T	$\Delta L/L_0$
644	0.153*
700	0.184*
755	0.212
810	0.296
866	0.276
922	0.310
977	0.344

CURVE 13

T	$\Delta L/L_0$
366	0.024*
422	0.043*
477	0.057*
533	0.070
588	0.078
644	0.084
700	0.092
755	0.097
810	0.105
866	0.115
922	0.125

CURVE 14

T	$\Delta L/L_0$
366	0.032*
422	0.063
477	0.097
533	0.139
588	0.167
644	0.202
700	0.241
755	0.279
810	0.324*
866	0.389*
922	0.425
977	0.448

CURVE 15

T	$\Delta L/L_0$
366	0.027*
422	0.063*
477	0.101*
533	0.142*
588	0.181*
644	0.226

CURVE 15 (cont.)

T	$\Delta L/L_0$
700	0.270
755	0.315
810	0.363*
866	0.406
922	0.462
977	0.519

CURVE 16

T	$\Delta L/L_0$
366	0.038*
422	0.083
477	0.107*
533	0.166
588	0.208
644	0.253
700	0.297
755	0.336*
810	0.397
866	0.446
922	0.503
977	0.549*

CURVE 17*

T	$\Delta L/L_0$
366	0.022
422	0.061
477	0.097
533	0.137
588	0.175
644	0.218
700	0.261
755	0.303
810	0.364
866	0.412
922	0.446
977	0.448

CURVE 18

T	$\Delta L/L_0$
366	0.099
422	0.178
477	0.258
533	0.342
588	0.418
644	0.499
700	0.579

CURVE 18 (cont.)

T	$\Delta L/L_0$
755	0.658
810	0.739
866	0.818
922	0.900
977	0.972

CURVE 19

T	$\Delta L/L_0$
293	0.000*
323	0.007
373	0.022
423	0.039*
473	0.062*
523	0.083
573	0.103
623	0.121
673	0.138
723	0.155
773	0.171
823	0.187
873	0.203
923	0.221
973	0.243
1023	0.269
1073	0.295
1077	0.297

CURVE 20

T	$\Delta L/L_0$
293	0.000*
323	0.003*
373	0.011*
423	0.024
473	0.041
523	0.058*
573	0.071
623	0.084
673	0.101
723	0.120
773	0.140
823	0.162*
873	0.182
923	0.204*
973	0.224
1023	0.245
1073	0.267
1074	0.268*

* Not shown in figure.

DATA TABLE 351. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERAMICS (continued)

T	$\Delta L/L_0$
CURVE 21*	
293	0.000
323	0.005
373	0.016
423	0.033
473	0.051
523	0.062
573	0.077
623	0.092
673	0.108
723	0.124
773	0.140
823	0.159
873	0.176
923	0.194
973	0.213
1023	0.234
1073	0.259
CURVE 22*	
293	0.000
323	0.004
373	0.014
423	0.028
473	0.041
523	0.055
573	0.070
623	0.085
673	0.100
723	0.114
773	0.128
823	0.143
873	0.161
923	0.181
973	0.201
1023	0.221
1073	0.243
1081	0.247
CURVE 23	
293	0.000*
323	0.003*
373	0.011*
423	0.024*
473	0.039*
523	0.053
573	0.065*

T	$\Delta L/L_0$
CURVE 23 (cont.)	
623	0.077*
673	0.090*
723	0.103*
773	0.118
823	0.132*
873	0.148
923	0.166
973	0.184
1023	0.203
1073	0.226
1077	0.228
CURVE 24*	
293	0.000
323	0.003
373	0.011
423	0.020
473	0.032
523	0.044
573	0.056
623	0.068
673	0.079
723	0.091
773	0.104
823	0.120
873	0.138
923	0.157
973	0.176
1023	0.195
1073	0.216
1084	0.220
CURVE 25	
373	-0.001
473	-0.002
573	0.000
673	0.004
773	0.012
873	0.029
973	0.040
CURVE 26*	
373	-0.001
473	-0.003
573	0.000

T	$\Delta L/L_0$
CURVE 26 (cont.)*	
673	0.007
773	0.016
873	0.027
973	0.035
CURVE 27*	
373	-0.001
473	-0.002
573	0.001
673	0.007
773	0.019
873	0.031
973	0.036
CURVE 28	
373	-0.010*
473	-0.022*
573	-0.033
673	-0.041
773	-0.046
873	-0.047
973	-0.044
CURVE 29	
373	-0.077
473	-0.173
573	-0.089
673	-0.092
773	-0.092
873	-0.090
973	-0.084
CURVE 30	
373	0.018*
473	0.040*
573	0.056*
673	0.071
773	0.087
873	0.102
973	0.117
CURVE 31	
373	0.015*

T	$\Delta L/L_0$
CURVE 31 (cont.)	
473	0.034*
573	0.047*
673	0.057*
773	0.067*
873	0.077
973	0.087
CURVE 32	
373	0.012*
401	0.024
437	0.042
461	0.054
490	0.070
509	0.083
534	0.101*
563	0.124
635	0.180
704	0.233
789	0.297*
866	0.358
900	0.383
941	0.411
987	0.439
1016	0.455
1038	0.468*
1061	0.479
1097	0.494*
1119	0.502
1145	0.510
1171	0.516
1206	0.522
1239	0.525
1273	0.526
CURVE 33	
303	0.000
333	-0.001
363	-0.002
393	-0.004
423	-0.006
453	-0.008
483	-0.009
513	-0.010
543	-0.011
573	-0.012*
603	-0.013

T	$\Delta L/L_0$
CURVE 33 (cont.)	
633	-0.014
663	-0.014
693	-0.014
723	-0.013
753	-0.012
783	-0.011
813	-0.010
843	-0.008
873	-0.006
903	-0.003
933	0.000
963	0.004
973	0.005
CURVE 34	
303	0.000*
333	-0.005*
363	-0.008*
393	-0.011*
423	-0.014*
453	-0.018*
483	-0.021*
513	-0.025
543	-0.028*
573	-0.031*
603	-0.034*
633	-0.036*
663	-0.037*
693	-0.038*
723	-0.039
753	-0.039
783	-0.039
813	-0.039
843	-0.038
873	-0.036*
903	-0.034
933	-0.032
963	-0.029
973	-0.028*
CURVE 35*	
303	0.000*
333	-0.002*
363	-0.004
393	-0.006
423	-0.007

T	$\Delta L/L_0$
CURVE 35 (cont.)*	
453	-0.009
483	-0.010
513	-0.011
543	-0.012
573	-0.012
603	-0.012
633	-0.012
663	-0.012
693	-0.011
723	-0.010
753	-0.009
783	-0.007
813	-0.005
843	-0.002
873	0.001
903	0.005
933	0.009
963	0.014
973	0.015
CURVE 36*	
303	0.000
333	-0.001
363	-0.002
393	-0.002
423	-0.004
453	-0.004
483	-0.004
513	-0.004
543	-0.004
573	-0.003
603	-0.002
633	-0.002
663	0.000
693	0.001
723	0.002
753	0.004
783	0.006
813	0.008
843	0.010
873	0.012
903	0.015
933	0.018
963	0.021
971	0.022

* Not shown in figure.

DATA TABLE 351. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERAMICS (continued)

T	$\Delta L/L_0$
CURVE 37*	
303	0.000
333	0.000
363	-0.001
393	-0.001
423	-0.002
453	-0.003
483	-0.004
513	-0.006
543	-0.006
573	-0.007
603	-0.007
633	-0.007
663	-0.007
693	-0.006
723	-0.005
753	-0.004
783	-0.002
813	0.000
843	0.002
873	0.006
903	0.010
933	0.016
963	0.022
971	0.022
CURVE 38*	
323	0.000
333	-0.001
363	-0.002
393	-0.004
423	-0.004
453	-0.005
483	-0.005
513	-0.005
543	-0.005
573	-0.004
603	-0.004
633	-0.002
663	-0.001
693	0.001
723	0.004
753	0.007
783	0.010
813	0.015
843	0.019
873	0.025
903	0.033

T	$\Delta L/L_0$
CURVE 38 (cont.)*	
933	0.044
963	0.054
973	0.055
CURVE 39	
323	0.000*
333	0.000*
363	-0.001*
393	-0.001*
423	-0.001*
453	-0.001*
483	-0.001*
513	0.000
543	0.001*
573	0.002*
603	0.003*
633	0.005
663	0.007
693	0.010
723	0.012
753	0.016
783	0.020
813	0.024
843	0.029
873	0.034*
903	0.040
933	0.047
963	0.055
973	0.058*
CURVE 40*	
298	0.004
973	0.550
CURVE 41*	
298	0.004
973	0.551
CURVE 42	
298	0.004*
973	0.612

T	$\Delta L/L_0$
CURVE 43*	
298	0.003
973	0.454
CURVE 44	
298	0.005*
973	0.717
CURVE 45*	
298	0.005
973	0.711
CURVE 46	
298	0.005
973	0.734
CURVE 47	
306	0.044
311	0.061
366	0.262
422	0.477
478	0.700
533	0.969
589	1.238
644	1.513
700	1.781
755	2.075
811	2.371
866	2.674
922	2.992
978	3.383
CURVE 48	
306	0.044*
311	0.061*
366	0.262*
422	0.489*
478	0.725
533	1.000
589	1.250*
644	1.530
700	1.822
755	2.134
811	2.422

T	$\Delta L/L_0$
CURVE 48 (cont.)	
866	2.743
922	3.049
978	3.406
CURVE 49	
306	0.044*
311	0.061*
366	0.262*
422	0.489*
478	0.754*
533	1.046
589	1.322
644	1.621
700	1.914
755	2.221
811	2.517
866	2.847
922	3.191
978	3.538
CURVE 50	
306	0.044*
311	0.061*
366	0.262*
422	0.489*
478	0.752*
533	1.034*
589	1.308
644	1.598
700	1.859
755	2.168
811	2.479
866	2.796
922	3.126
978	3.467
CURVE 51	
323	0.034
373	0.091
423	0.140
473	0.183
523	0.239
573	0.290
623	0.341
673	0.399

T	$\Delta L/L_0$
CURVE 51 (cont.)	
723	0.458
773	0.527
823	0.617
873	0.721
923	0.753
943	0.763
CURVE 52	
323	0.034*
373	0.091*
423	0.140*
473	0.183*
523	0.239*
573	0.290*
623	0.341*
673	0.399*
723	0.448*
773	0.509
823	0.591
873	0.695
923	0.725
943	0.731
CURVE 53*	
323	0.023
373	0.061
423	0.093
473	0.123
523	0.158
573	0.191
623	0.227
673	0.264
723	0.300
773	0.337
823	0.391
873	0.479
923	0.518
943	0.527
CURVE 54	
293	0.000*
323	0.013*
373	0.040*
423	0.073*
473	0.124

T	$\Delta L/L_0$
CURVE 54 (cont.)	
523	0.198
573	0.276
623	0.370
673	0.479
723	0.707
773	0.879
823	1.306
873	1.407
923	1.400
973	1.390
1023	1.376
1073	1.368
1123	1.359
1173	1.349
1223	1.320
1241	1.258
CURVE 55*	
293	0.000
323	0.018
373	0.051
423	0.092
473	0.154
523	0.237
573	0.309
623	0.403
673	0.491
723	0.634
773	0.828
823	1.280
873	1.366
923	1.369
973	1.363
1023	1.353
1073	1.340
1123	1.325
1173	1.303
1223	1.273
1231	1.257
CURVE 56	
324	0.004*
344	0.008
359	0.012*
374	0.016*
393	0.019

* Not shown in figure.

DATA TABLE 351. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERAMICS (continued)

T	$\Delta L/L_0$
CURVE 56 (cont.)	
414	0.023*
482	0.032
514	0.039
571	0.045
610	0.049
623	0.048
633	0.046
643	0.047
646	0.048*
651	0.050
658	0.050
664	0.052
693	0.070
CURVE 57	
317	0.011*
336	0.019*
358	0.023*
377	0.034*
398	0.048
416	0.058
443	0.073
473	0.086*
496	0.099
525	0.112
558	0.124
595	0.137
617	0.144
647	0.148*
653	0.152
679	0.162
703	0.174
723	0.186
CURVE 58*	
293	0.000
300	0.002
304	0.004
312	0.007
320	0.009
327	0.012
334	0.016
342	0.019
349	0.022
358	0.025
364	0.027

T	$\Delta L/L_0$
CURVE 58 (cont.)*	
369	0.028
375	0.030
380	0.031
389	0.033
397	0.034
412	0.038
425	0.039
428	0.039
432	0.040
443	0.039
457	0.039
468	0.037
475	0.036
480	0.035
487	0.033
493	0.033
497	0.031
501	0.030
507	0.028
512	0.026
516	0.023
522	0.021
527	0.019
534	0.016
539	0.014
543	0.011
547	0.010
555	0.006
561	0.004
565	0.001
570	-0.001
574	-0.003
CURVE 59	
304	0.009*
308	0.012*
313	0.016*
336	0.019*
352	0.021*
355	0.018*
358	0.016*
362	0.014*
367	0.012*
373	0.009*
388	-0.001*
405	-0.011
423	-0.023*

T	$\Delta L/L_0$
CURVE 59 (cont.)	
436	-0.035*
450	-0.043
463	-0.053*
475	-0.058
492	-0.070*
510	-0.082
527	-0.093*
548	-0.104
566	-0.117*
587	-0.128*
607	-0.141
623	-0.154*
626	-0.155*
632	-0.157
639	-0.157
646	-0.155*
651	-0.154*
659	-0.150
668	-0.149*
671	-0.146*
675	-0.142
697	-0.132
712	-0.119*
732	-0.106*
752	-0.094
768	-0.084*
788	-0.070*
798	-0.058
812	-0.043*
823	-0.036*
CURVE 60	
328	0.004*
342	0.007*
360	0.009*
370	0.011*
387	0.014
403	0.017*
417	0.020
437	0.026
448	0.030
465	0.035
471	0.036*
482	0.040*
497	0.046
510	0.051
522	0.057*

T	$\Delta L/L_0$
CURVE 60 (cont.)	
537	0.062*
550	0.067
562	0.073
577	0.078*
CURVE 61*	
273	0.005
291	0.001
309	-0.006
321	-0.009
339	-0.014
351	-0.016
367	-0.019
384	-0.021
410	-0.024
433	-0.036
446	-0.026
474	-0.026
486	-0.036
499	-0.025
514	-0.023
525	-0.021
539	-0.017
550	-0.014
563	-0.009
574	-0.004
585	0.000
594	0.005
602	0.009
613	0.016
621	0.022
628	0.026
CURVE 62	
269	0.008
293	0.000*
327	-0.015
339	-0.021
350	-0.025
363	-0.029
374	-0.032*
386	-0.035
394	-0.037
404	-0.039
418	-0.041
433	-0.042

T	$\Delta L/L_0$
CURVE 62 (cont.)	
448	-0.043*
468	-0.043
491	-0.041
500	-0.040
520	-0.036
535	-0.032
544	-0.028*
571	-0.016*
593	-0.006
612	0.001
621	0.005
633	0.008*
CURVE 63*	
269	0.010
288	-0.003
318	-0.011
325	-0.016
338	-0.021
351	-0.026
364	-0.030
381	-0.036
398	-0.040
409	-0.044
421	-0.046
439	-0.049
452	-0.051
460	-0.052
476	-0.052
491	-0.051
516	-0.048
536	-0.044
553	-0.040
569	-0.035
591	-0.026
CURVE 64*	
273	0.000
309	0.001
404	0.004
496	0.006
571	0.008
636	0.010

T	$\Delta L/L_0$
CURVE 65	
273	0.000
296	0.002
322	0.006
343	0.010*
366	0.013*
390	0.018*
410	0.022
433	0.028*
465	0.037*
516	0.052*
565	0.066*
600	0.077
625	0.084*
650	0.090
CURVE 66*	
269	-0.006
284	-0.003
296	0.001
308	0.005
319	0.009
331	0.016
346	0.029
359	0.035
376	0.048
402	0.068
419	0.080
443	0.098
457	0.109
CURVE 67*	
293	0.000
301	0.001
308	0.002
317	0.004
324	0.006
331	0.007
347	0.012
385	0.013
405	0.015
413	0.015
421	0.018
430	0.022
437	0.024
446	0.027
455	0.032
480	0.042

* Not shown in figure.

DATA TABLE 351. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERAMICS (continued)

T	$\Delta L/L_0$
CURVE 68*	
293	0.000
299	0.002
309	0.003
316	0.004
324	0.004
334	0.005
344	0.004
352	0.001
360	-0.005
365	-0.009
373	-0.012
385	-0.011
397	-0.009
406	-0.006
416	-0.006
421	-0.003
431	0.000
441	0.004
462	0.010
472	0.014
CURVE 69*	
293	0.000
299	0.001
308	0.002
316	0.004
324	0.004
336	0.005
345	0.005
353	0.004
360	0.004
368	0.003
378	0.002
394	0.002
412	0.006
433	0.013
482	0.036
506	0.048
CURVE 70*	
299	0.000
307	0.000
316	0.000
323	0.001
330	0.002
339	0.003
CURVE 70 (cont.)*	
347	0.006
356	0.008
363	0.010
373	0.012
381	0.013
388	0.015
397	0.017
404	0.019
416	0.023
425	0.025
436	0.031
449	0.034
458	0.037
469	0.044
477	0.048
488	0.054
499	0.058
508	0.067
CURVE 71*	
296	0.000
304	0.001
311	0.002
320	0.004
328	0.007
337	0.009
345	0.009
353	0.008
361	0.008
369	0.009
377	0.008
387	0.008
393	0.008
400	0.009
408	0.011
417	0.012
425	0.014
433	0.015
441	0.015
450	0.018
458	0.021
465	0.022
486	0.028
503	0.035
CURVE 72*	
293	0.000
302	0.001
309	0.002
317	0.003
326	0.003
333	0.003
341	0.004
349	0.004
358	0.004
366	0.004
374	0.004
382	0.005
390	0.005
399	0.007
407	0.010
422	0.014
468	0.024
499	0.040
CURVE 73*	
293	0.000
299	0.000
306	0.002
316	0.004
326	0.006
335	0.010
342	0.012
350	0.013
359	0.017
366	0.019
376	0.022
384	0.022
395	0.025
408	0.029
414	0.030
423	0.033
431	0.036
439	0.039
446	0.042
455	0.046
463	0.049
475	0.055
483	0.057
496	0.064
CURVE 74*	
300	0.007
366	0.074
477	0.215
588	0.374
699	0.544
735	0.629
753	0.712
755	0.713
758	0.707
CURVE 75*	
300	0.005
366	0.057
477	0.152
589	0.257
699	0.404
715	0.454
717	0.488
720	0.491
723	0.490
723	0.487
CURVE 76*	
300	0.005
366	0.055
477	0.146
588	0.248
699	0.353
769	0.428
810	0.491
833	0.564
850	0.627
853	0.621
CURVE 77*	
300	0.004
366	0.042
477	0.103
588	0.163
659	0.215
689	0.257
711	0.351
735	0.575
765	0.684
786	0.722
CURVE 77 (cont.)*	
804	0.743
806	0.741
807	0.735
CURVE 78*	
300	0.008
366	0.087
477	0.246
588	0.408
699	0.606
760	0.778
762	0.777
763	0.772
CURVE 79*	
300	0.007
366	0.074
477	0.215
588	0.372
699	0.525
810	0.680
877	0.777
889	0.835
887	0.863
891	0.867
894	0.862
CURVE 80*,‡	
533	0.112
810	0.242
922	0.295
CURVE 81*,‡	
533	0.186
810	0.401
922	0.490
CURVE 82*	
298	0.005
366	0.041
423	0.083
532	0.170
650	0.264
CURVE 82 (cont.)*	
700	0.308
778	0.372
869	0.454
980	0.552
1035	0.612
1093	0.686
CURVE 83*	
302	0.006
366	0.041
379	0.050
429	0.086
489	0.140
524	0.166
588	0.222
634	0.258
700	0.310
761	0.360
816	0.408
828	0.463
918	0.488
971	0.541
998	0.557
CURVE 84*	
302	0.006
366	0.039
400	0.065
457	0.110
518	0.156
571	0.197
627	0.242
681	0.286
739	0.334
794	0.378
822	0.401
CURVE 85*	
364	0.048
478	0.013
588	0.048
696	0.127
806	0.139
923	0.603
1023	0.694

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 351. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERAMICS (continued)

T	$\Delta L/L_0$
CURVE 85 (cont.)*	
1143	0.627
1250	0.689
1366	0.473
1476	0.091
1589	-0.312
1710	-0.880
1763	-1.164
CURVE 86*	
364	0.035
477	0.117
590	0.226
699	0.339
805	0.609
921	0.885
1030	0.998
1144	0.975

T	$\Delta L/L_0$
CURVE 86 (cont.)*	
1252	0.949
1366	0.911
1475	0.666
1589	0.292
1704	-0.200
1755	-0.436
CURVE 87*	
477	0.145
589	0.245
700	0.312
808	0.400
922	0.498
1029	0.572
1143	0.691
1252	0.774
1365	0.777

T	$\Delta L/L_0$
CURVE 87 (cont.)*	
1473	0.728
1588	0.679
1701	0.636
1752	0.613
CURVE 88*	
307	0.014
373	0.082
473	0.178
573	0.279
673	0.385
773	0.493
873	0.606
973	0.730
1002	0.761

T	$\Delta L/L_0$
CURVE 89*,‡	
300	0.007
325	0.032
350	0.059
375	0.087
400	0.116
425	0.144
450	0.172
475	0.200
500	0.228
525	0.255
550	0.283
575	0.310
600	0.337
625	0.367
650	0.399
675	0.437
700	0.481
725	0.544

T	$\Delta L/L_0$
CURVE 89 (cont.)*,‡	
750	0.532
775	0.524
800	0.516
825	0.523
850	0.530
875	0.544
900	0.561
925	0.575
950	0.593
975	0.610
1000	0.630
1025	0.650
1050	0.669
1075	0.690
1100	0.712
1125	0.735
1150	0.758
1174	0.779

DATA TABLE 351. COEFFICIENT OF THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERAMICS

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 80*,‡	
533	4.68
810	4.68
922	4.89
CURVE 81*,‡	
533	7.56
810	7.94
922	7.97
CURVE 89*,‡	
300	8.46
325	9.16
350	9.74
375	10.08
400	10.38

T	α
CURVE 89 (cont.)*,‡	
425	10.52
450	10.65
475	10.72
500	10.76
525	10.76
550	10.78
575	10.78
600	10.78
625	10.87
650	11.00
675	11.28
700	11.63
725	12.38
750	11.50
775	10.76
800	10.10
825	9.76

T	α
CURVE 89 (cont.)*,‡	
850	9.47
875	9.31
900	9.20
925	9.07
950	8.99
975	8.92
1000	8.89
1025	8.86
1050	8.82
1075	8.80
1100	8.80
1125	8.82
1150	8.82
1174	8.82

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

7. CERMETS

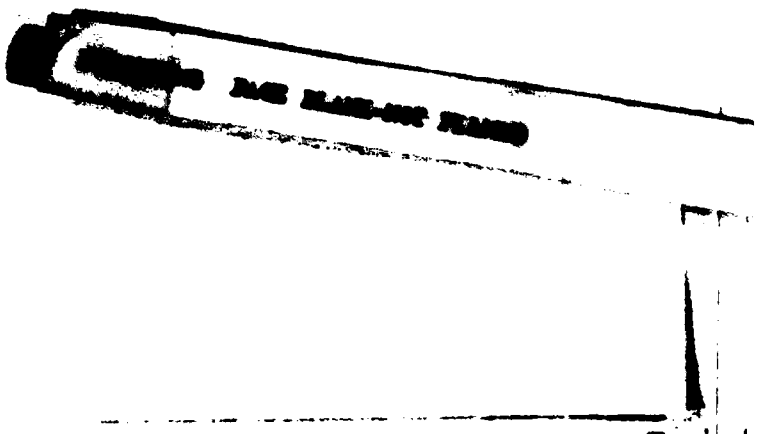
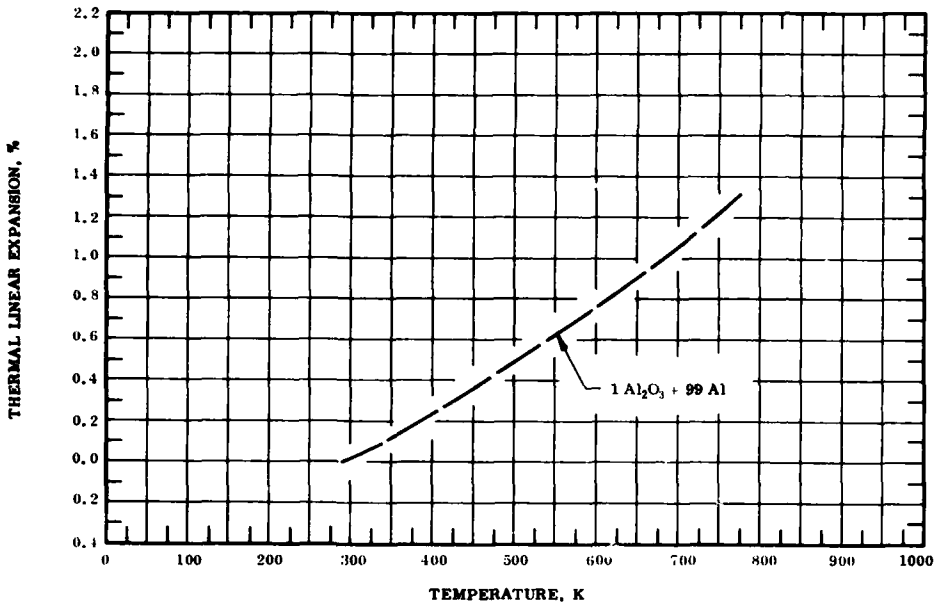


FIGURE AND TABLE NO. 352R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE + ALUMINUM Al_2O_3 + Al



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	22.0
350	0.127	22.7
400	0.243	23.5
450	0.362	24.4
500	0.490	25.5
550	0.620	26.8
600	0.755	28.2
650	0.900	29.8
700	1.053	31.6
750	1.220	33.5
775	1.301	34.5

REMARKS

The provisional values are based on the data for $1Al_2O_3$ + 99 Al cermet of density 2.7 g cm^{-3} and are considered accurate to within ±7% below 500 K and ± 10% above 500 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.629 + 2.184 \times 10^{-3} T - 4.525 \times 10^{-7} T^2 + 1.093 \times 10^{-9} T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ± 10%.

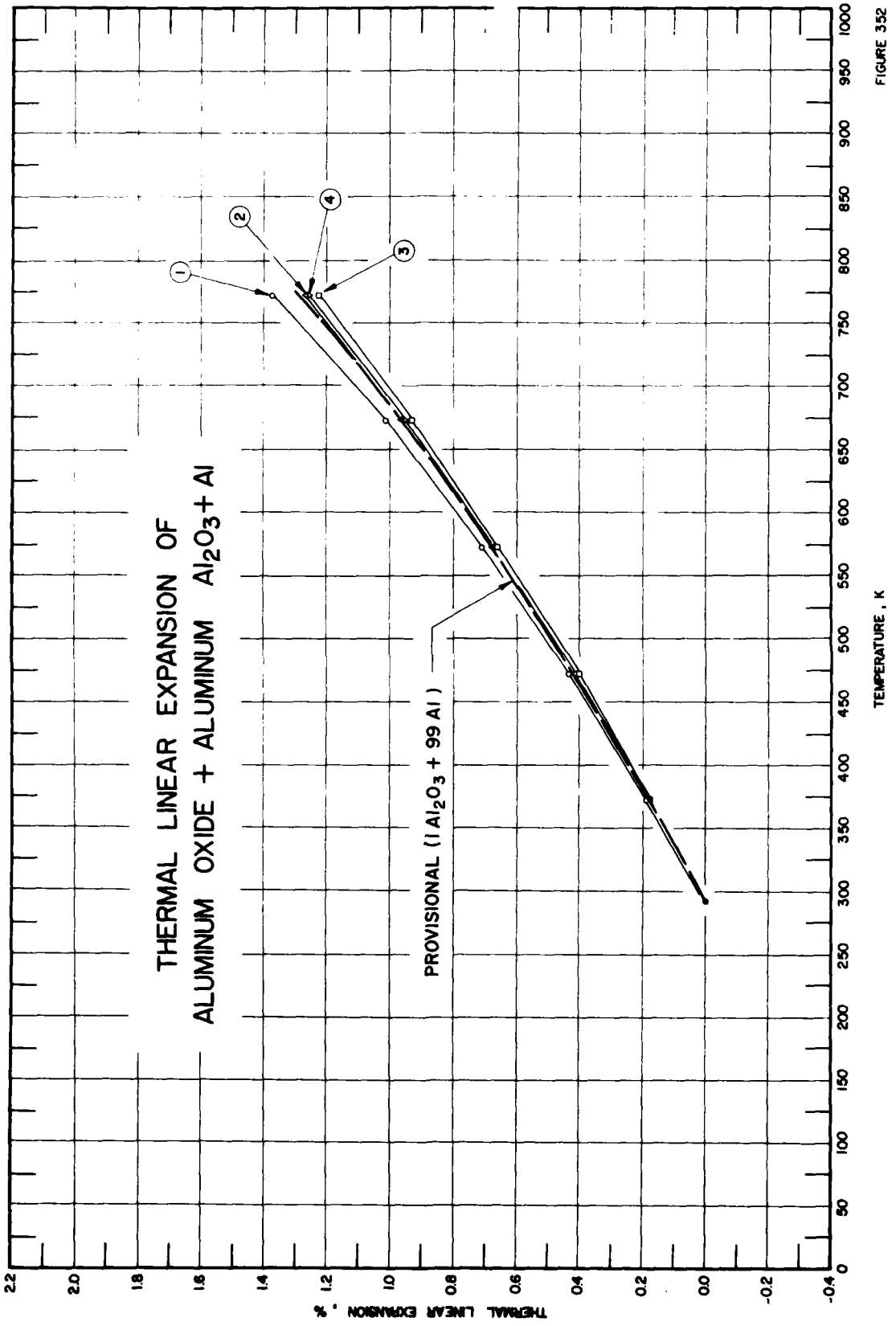

THERMAL LINEAR EXPANSION OF
ALUMINUM OXIDE + ALUMINUM Al_2O_3+ Al
PROVISIONAL (I Al_2O_3 + 99 Al)
1
2
3
4
THERMAL LINEAR EXPANSION , %
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
TEMPERATURE , K

FIGURE 352

SPECIFICATION TABLE 352. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE + ALUMINUM Al_2O_3 + Al

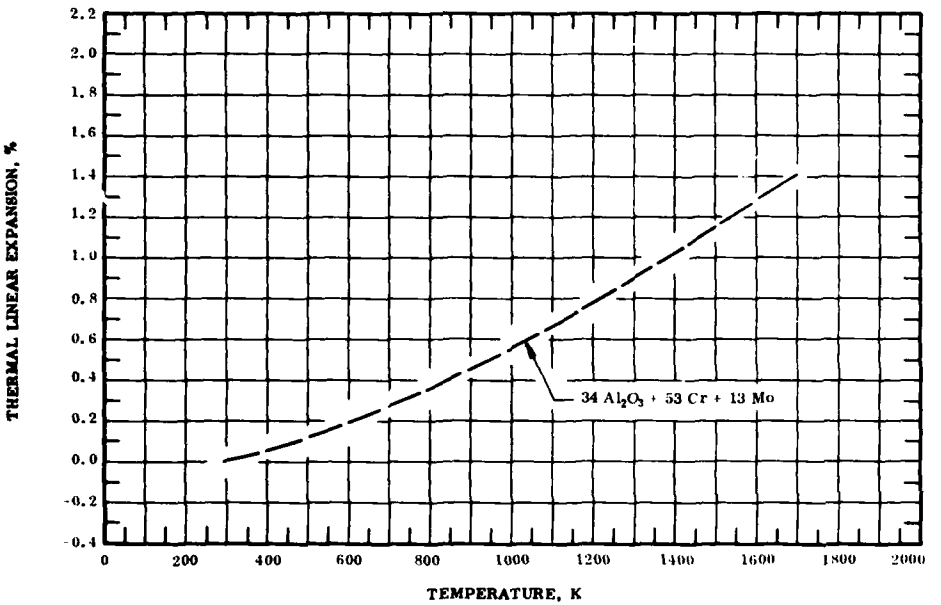
Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1009	Gerchikova, N.S., Kolobneu, N.I., Stepanova, M.G., and Fridlyander, I.N.	1963		293-773		Pressed rod made of sintered aluminum powder with 1% Al_2O_3; density 2.65-2.7 g cm^{-3}.
2	1009	Gerchikova, N.S., et al.	1963		293-773		Similar to the above specimen; density 2.70-2.71 g cm^{-3}.
3	1009	Gerchikova, N.S., et al.	1963		293-773		Similar to the above specimen; density 2.72-2.73 g cm^{-3}.
4	1009	Gerchikova, N.S., et al.	1963		293-773	SAP-1	Pressed semifinished product.

DATA TABLE 352. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE + ALUMINUM Al_2O_3 + Al

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 3	
293	0.000	293	0.000
373	0.187	373	0.174
473	0.437	473	0.405
573	0.711	573	0.661
673	1.018	673	0.935
773	1.378	773	1.229
CURVE 2		CURVE 4	
293	0.000	293	0.000
373	0.180	373	0.178
473	0.419	473	0.414
573	0.680	573	0.669
673	0.965	673	0.950
773	1.272	773	1.262

FIGURE AND TABLE NO. 353R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE + CHROMIUM + ΣX_i $Al_2O_3 + Cr + \Sigma X_i$



PROVISIONAL VALUES

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1})

T	$\Delta L/L_0$	α
293	0.000	4.3
400	0.052	5.5
500	0.113	6.5
600	0.185	7.5
700	0.263	8.4
800	0.351	9.2
900	0.445	10.0
1000	0.550	10.7
1100	0.661	11.3
1200	0.778	11.9
1300	0.900	12.4
1400	1.025	12.8
1500	1.154	13.2
1600	1.286	13.4
1700	1.422	13.6

REMARKS

The provisional values are based on the data for 34 Al_2O_3 + 53 Cr + 13 Mo cermet and are considered accurate to within ±7% below 1300 K and ±10% above 1300 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.074 + 6.294 \times 10^{-5} T + 6.758 \times 10^{-4} T^2 - 1.148 \times 10^{-10} T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

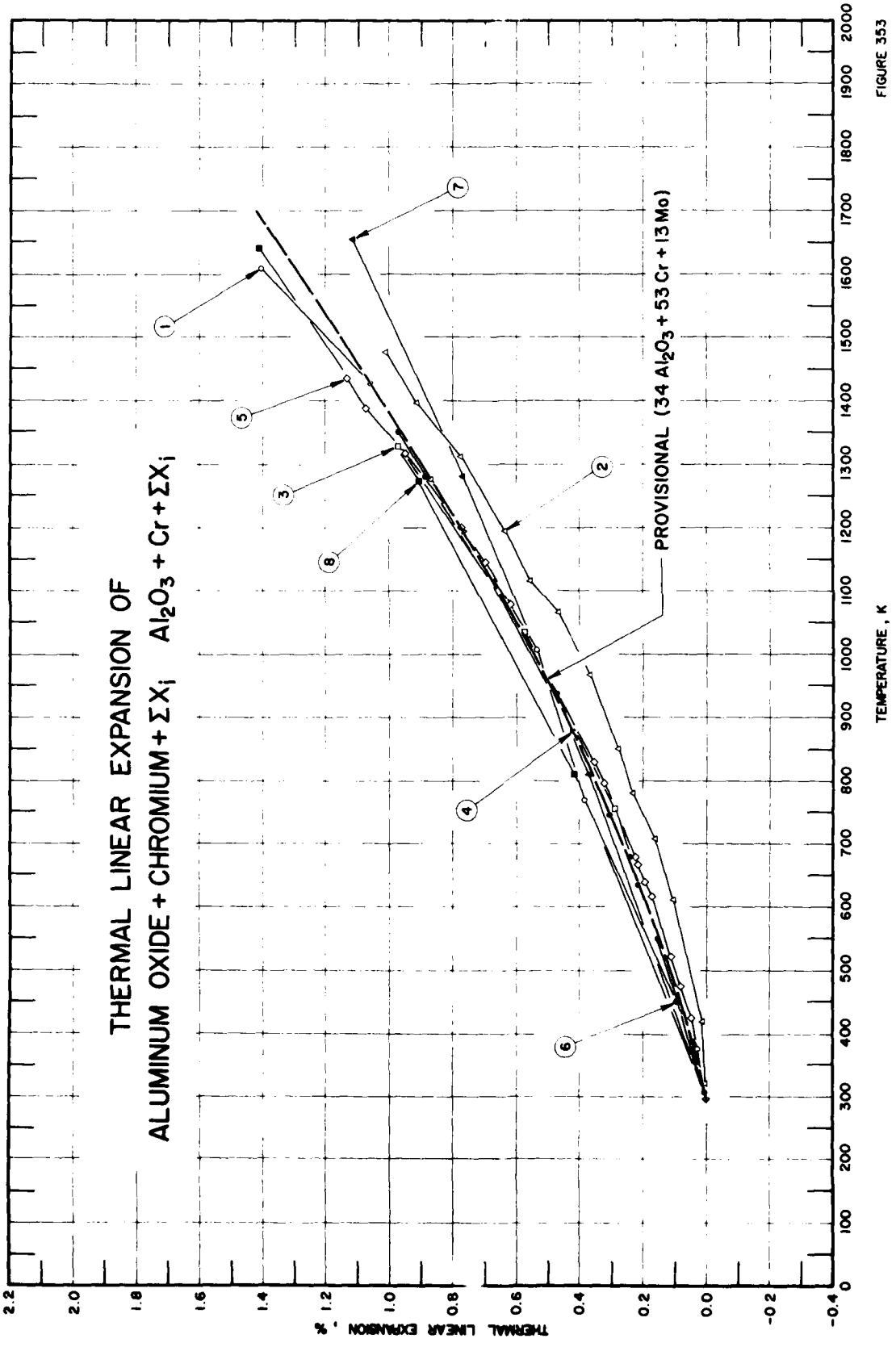

THERMAL LINEAR EXPANSION OF
ALUMINUM OXIDE + CHROMIUM + ΣXi Al2O3 + Cr + ΣXi
PROVISIONAL (34 Al2O3 + 53 Cr + 13 Mo)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
4
5
6
7
8

FIGURE 353

SPECIFICATION TABLE 353. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE + CHROMIUM + ΣX_i $Al_2O_3 + Cr + \Sigma X_i$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	57	Shevlin, T.S. and Hauck, C.A.	1954	L	305-1610	A-355.6-G	34.4 Al_2O_3, 52.5 Cr, 13.1 Mo; prepared from corundum form 0.05% maximum soda, Alcoa Grade T-61, milled to -25 μ, acid leached and supplied by Champion Spark Plug Co.; electrolytic, 99% minimum chromium content, -325 mesh, supplied by Charles Hardy, Inc. or Electrometallurgical Division, Union Carbide and Carbon Co.; hydrogen reduced, 99.75 minimum molybdenum content, -200 mesh supplied by Charles Hardy Inc.; run A; zero-point correction is 0.005%.
2	57	Shevlin, T.S. and Hauck, C.A.	1954	L	1477-321	A-355.6-G	Similar to the above specimen, run A, expansion measured with decreasing temperature; zero-point correction is -0.193%.
3	57	Shevlin, T.S. and Hauck, C.A.	1954	L	305-1328	A-355.6-G	Similar to the above specimen, run B, expansion measured with increasing temperature; zero-point correction is 0.008%.
4	57	Shevlin, T.S. and Hauck, C.A.	1954	L	1194-305	A-355.6-G	Similar to the above specimen, run B, expansion measured with decreasing temperature; zero-point correction is -0.005%.
5	57	Shevlin, T.S. and Hauck, C.A.	1954	L	300-1433	A-355.6-G	Similar to the above specimen, run C, expansion measured with increasing temperature; zero-point correction is 0.003%.
6	57	Shevlin, T.S. and Hauck, C.A.	1954	L	1350-300	A-355.6-G	Similar to the above specimen, run C, expansion measured with decreasing temperature; zero-point correction is 0.003%.
7	373	Anthony, F.M. and Pearl, H.A.	1960		299-1655	$Al_2O_3 + Cr + W$	LT-2, 60 W, 15 Al_2O_3, 25 Cr; specimen 3/8 in. diameter by 3 in. long; sintered at 1950 K; zero-point correction is 0.004%.
8	373	Anthony, F.M. and Pearl, H.A.	1960		299-1641	LT-1B, E-24	59 Cr, 19 Al_2O_3, 20 Mo, 2 TiO_2; specimen 3/8 in. diameter by 3 in. long; sintered at about 1866 K in hydrogen-argon atmosphere; zero-point correction is 0.005%; reported error < 5%

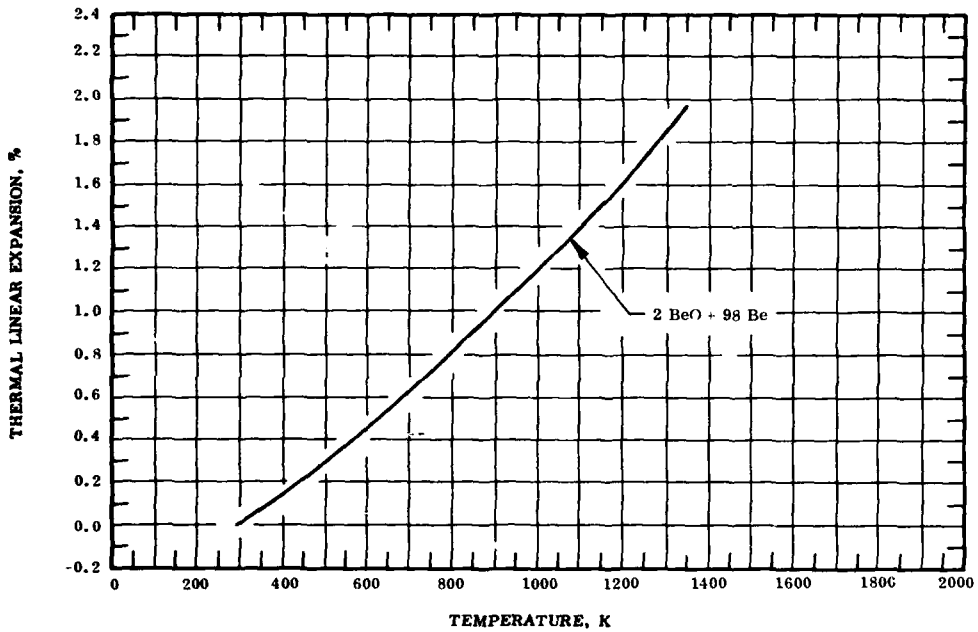
DATA TABLE 353. THERMAL LINEAR EXPANSION OF ALUMINUM OXIDE + CHROMIUM + ΣX_i $Al_2O_3 + Cr + \Sigma X_i$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
305	0.005
377	0.032
769	0.387
1005	0.535
1277	0.869
1427	1.058
1610	1.405
CURVE 2	
1477	1.016
1397	0.917
1311	0.774
1194	0.635
1116	0.557
1066	0.466
966	0.367
850	0.278
780	0.236
708	0.162
611	0.106
419	0.014
321	0.003
CURVE 3	
305	0.008*
755	0.288
1033	0.575
1328	0.974
CURVE 4	
1194	0.765
880	0.422
305	0.009*
CURVE 5	
300	0.003
425	0.053
475	0.085
522	0.114
616	0.176
639	0.195
CURVE 5 (cont.)	
666	0.218
678	0.226
797	0.321
828	0.354
1078	0.620
1144	0.698
1200	0.773
1316	0.950
1386	1.076
1433	1.136
CURVE 6	
1350	0.975
1280	0.886
1191	0.765*
936	0.473
744	0.302
678	0.241
633	0.217
550	0.157
450	0.096
353	0.035
300	0.004*
CURVE 7	
299	0.004*
810	0.372
1280	0.770
1655	1.119
CURVE 8	
299	0.005*
810	0.418
1272	0.907
1641	1.416

* Not shown in figure.

FIGURE AND TABLE NO. 354R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF BERYLLIUM OXIDE + BERYLLIUM BeO + Be



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	12.4
400	0.141	14.0
500	0.290	15.4
600	0.450	16.7
700	0.622	17.7
800	0.804	18.6
900	1.000	19.4
1000	1.191	20.0
1100	1.393	20.4
1200	1.600	20.7
1300	1.845	20.8
1350	1.985	21.0

REMARKS

The recommended values for 2BeO + 98Be cerment are based on the data of Curves 3, 5, and 6 and the thermal expansion values of the pure BeO and Be. These values are considered accurate to within ±5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.285 + 6.866 \times 10^{-4}\, T + 1.057 \times 10^{-6}\, T^2 - 2.675 \times 10^{-10}\, T^3$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equation and are considered accurate to about ±7%.

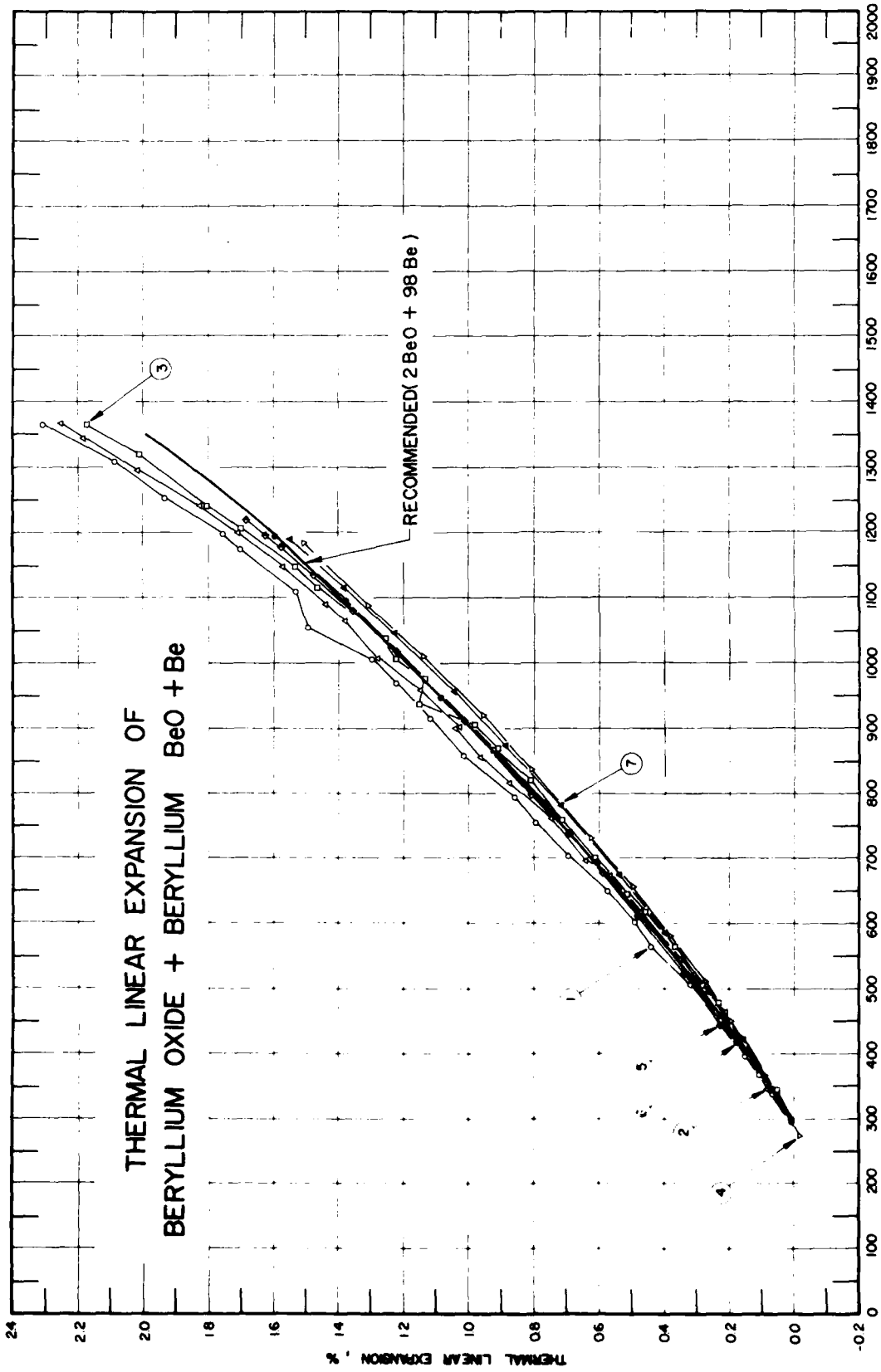

THERMAL LINEAR EXPANSION OF
BERYLLIUM OXIDE + BERYLLIUM BeO + Be
RECOMMENDED(2 BeO + 98 Be)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
24
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 354

SPECIFICATION TABLE 354. THERMAL LINEAR EXPANSION OF BERYLLIUM OXIDE + BERYLLIUM BeO + Be

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	455	Fieldhouse, I.B., Hedge, J.C., Long, J.I., and Waterman, T.E.	1958	T	338-1366	YB 9052 Beryllium	99.16 Be and 0.84 BeO.
2	455	Fieldhouse, I.B., et al.	1958	T	295-1368	Beryllium YB 9053	98.51 Be and 1.49 BeO; zero-point correction is 0.004%.
3	455	Fieldhouse, I.B., et al.	1958	T	2[illegible]-1366	Beryllium YB 9054	98.32 Be and 1.68 BeO; zero-point correction is 0.007%.
4	1010	Barton, J.E. and Fulkerson, S.D.	1956		273-1184		99.00 Be and 1.0 BeO; hot-pressed beryllium containing BeO; sample 1 in. long; supplied by the Brush Beryllium Company; heating rate 2.5 °C/min; zero-point correction is -1.493%.
5	1010	Barton, J.E. and Fulkerson, S.D.	1956		273-1220		98.5 Be and 1.5 BeO; similar to the above specimen zero-point correction is -1.426%.
6	1010	Barton, J.E. and Fulkerson, S.D.	1956		273-1194		98.0 Be and 2.0 BeO; similar to the above specimen; zero-point correction is -1.442%.
7	1010	Barton, J.E. and Fulkerson, S.D.	1956		273-1190		97.0 Be and 3.0 BeO; similar to the above specimen; zero-point correction is -1.434%.
8	1011	Greenspan, J.	1953		293-1173		< 7 Be; dimension 1/2 in. diameter, 1 in. long; hot-pressed the mixture of beryllium and beryllium oxide at 2000 psi at the temperatures between 1973 K and 2073 K in vacuum.

DATA TABLE 354. THERMAL LINEAR EXPANSION OF BERYLLIUM OXIDE + BERYLLIUM BeO + Be

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
338	0.067
397	0.153
422	0.206*
451	0.226
486	0.295*
507	0.320
534	0.362*
564	0.441
601	0.490
618	0.534*
649	0.575
680	0.648*
702	0.696
730	0.764*
753	0.794
783	0.865*
795	0.859
810	0.919*
812	0.897*
839	0.957*
858	1.015
873	1.034*
888	1.076*
915	1.119
935	1.168*
969	1.222
984	1.258*
1005	1.298
1039	1.394*
1054	1.497
1080	1.486*
1110	1.534
1138	1.651*
1175	1.701
1198	1.758
1238	1.895*
1252	1.935
1310	2.090
1366	2.310

CURVE 2

T	$\Delta L/L_0$
295	0.004
319	0.046*
346	0.082

CURVE 2 (cont.)

T	$\Delta L/L_0$
377	0.142*
425	0.171
467	0.212
510	0.298
545	0.350
588	0.426*
617	0.471
639	0.529*
672	0.567
697	0.639
730	0.699*
761	0.747
785	0.805*
817	0.876
837	0.928*
855	0.962
868	0.959*
899	1.040
901	1.029
921	1.078*
925	1.082*
958	1.149
987	1.200*
1007	1.280
1035	1.316*
1064	1.379
1090	1.441
1124	1.515*
1148	1.570
1177	1.665*
1200	1.712
1240	1.827
1272	1.921*
1297	2.020
1321	2.076*
1343	2.186
1368	2.254

CURVE 3

T	$\Delta L/L_0$
299	0.007
344	0.055
369	0.107
398	0.152*
425	0.180*

CURVE 3 (cont.)

T	$\Delta L/L_0$
452	0.234*
479	0.234
506	0.285
536	0.315*
564	0.368
589	0.416*
618	0.461
646	0.513
675	0.547*
700	0.613
730	0.651*
758	0.712
785	0.745*
820	0.809
832	0.834*
867	0.923
869	0.907
904	0.982
934	1.056*
935	1.157
975	1.135
1007	1.227
1038	1.254
1073	1.356*
1117	1.464
1149	1.534
1179	1.634*
1207	1.701
1240	1.802
1273	1.883*
1320	2.015
1338	2.086*
1366	2.177

CURVE 4

T	$\Delta L/L_0$
273	-0.021
293	0.000*
368	0.089
451	0.195
511	0.279
581	0.381
656	0.496
732	0.622
837	0.807

CURVE 4 (cont.)

T	$\Delta L/L_0$
920	0.956
1009	1.140
1088	1.307
1184	1.507

CURVE 5

T	$\Delta L/L_0$
273	-0.026*
293	0.000*
446	0.224
522	0.339
612	0.481
678	0.589
738	0.693
799	0.806
911	1.013
1018	1.221
1080	1.354
1136	1.474
1178	1.575
1197	1.624
1220	1.686

CURVE 6

T	$\Delta L/L_0$
273	-0.024*
293	0.000*
346	0.067*
420	0.176
514	0.314
618	0.479*
693	0.602
784	0.762
857	0.901
948	1.083
1020	1.255*
1093	1.377
1194	1.593

CURVE 7

T	$\Delta L/L_0$
273	-0.022*
293	0.000*
367	0.089*
421	0.159

CURVE 7 (cont.)

T	$\Delta L/L_0$
495	0.262
586	0.396
674	0.538
782	0.717
873	0.885
957	1.046
1047	1.230
1115	1.382
1190	1.550

CURVE 8*

T	$\Delta L/L_0$
293	0.000
424	0.077
573	0.162
723	0.250
973	0.504
1121	0.645
1173	0.705

* Not shown in figure.

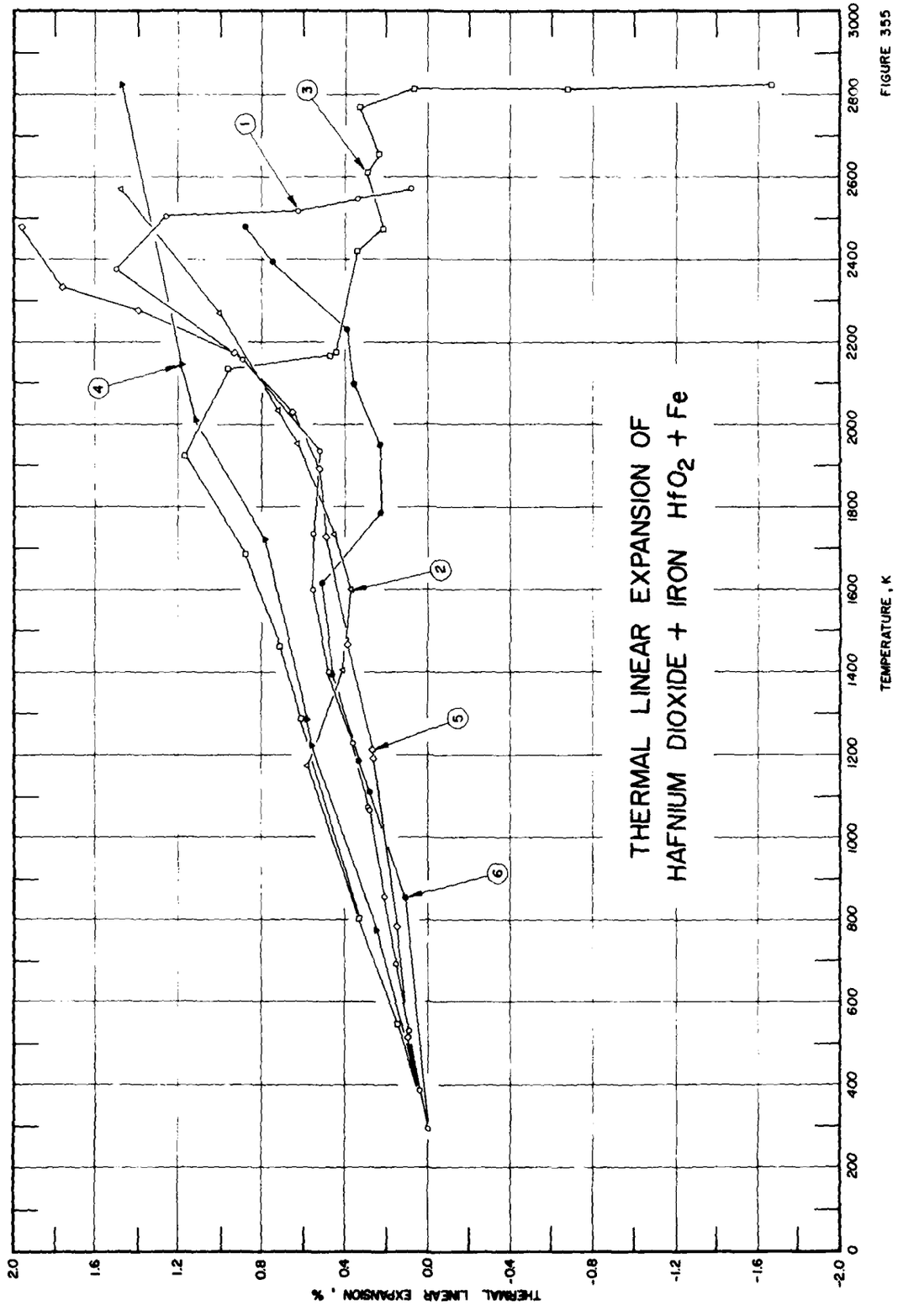

THERMAL LINEAR EXPANSION OF
HAFNIUM DIOXIDE + IRON HfO_2 + Fe
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.0
1.6
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
-1.6
-2.0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
1
2
3
4
5
6

FIGURE 355

SPECIFICATION TABLE 355. THERMAL LINEAR EXPANSION OF HAFNIUM DIOXIDE + IRON HfO_2 + Fe

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	63	Pears, C.D. and Oglesby, S.	1962	L	293-2572	RUN E-15	2.5 Fe, 0.3 Mg, 0.1 Ti, 0.1 Ca impurities; specimen 2.240 in. long before test, 2.238 in. after test; obtained from Zirconium Corp. of America; density at 25 C 9.00 g cm^{-3} before exposure, 8.93 g cm^{-3} after exposure; expansion measured in Helium atmosphere; reported error 5%.
2	63	Pears, C.D. and Oglesby, S.	1962	L	2572-293	RUN E-15	The above specimen; expansion measured with decreasing temperature; zero-point correction is 1.40%.
3	63	Pears, C.D. and Oglesby, S.	1962	L	293-2825	RUN E-16	The above specimen; 2.234 in. long after test; expansion measured with increasing temperature on second test; reported error 5%.
4	63	Pears, C.D. and Oglesby, S.	1962	L	2825-293	RUN E-16	The above specimen; expansion measured with decreasing temperature on second test; zero-point correction is 3.14%.
5	63	Pears, C.D. and Oglesby, S.	1962	L	293-2480	RUN E-18	The above specimen; 2.837 in. long before test, 2.875 in. after test; expansion measured with increasing temperature on third test; reported error 5%.
6	63	Pears, C.D. and Oglesby, S.	1962	L	2480-293	RUN E-18	The above specimen; expansion measured with decreasing temperature on third test; zero-point correction is -1.08%.

DATA TABLE 355. THERMAL LINEAR EXPANSION OF HAFNIUM DIOXIDE + IRON HfO_2 + Fe

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
293	0.00
385	0.04
530	0.09
692	0.15
857	0.21
1065	0.28
1072	0.29
1227	0.36
1399	0.47
1599	0.55
1733	0.55
1935	0.52
2158	0.89
2377	1.50
2505	1.26
2519	0.63
2547	0.34
2572	0.08

CURVE 2

T	$\Delta L/L_0$
2572	1.48
2269	1.01
2033	0.72
1952	0.63
1733	0.45
1600	0.37
1402	0.41
1172	0.58
293	0.00*

CURVE 3

T	$\Delta L/L_0$
293	0.00*
544	0.15
801	0.33
1284	0.61
1283	0.61*
1460	0.71

CURVE 3 (cont.)

T	$\Delta L/L_0$
1683	0.88
1922	1.17
2133	0.96
2166	0.47
2177	0.44
2422	0.34
2477	0.22
2611	0.29
2658	0.24
2769	0.33
2876	0.07
2816	-0.67
2825	-1.66

CURVE 4

T	$\Delta L/L_0$
2825	1.48
2144	1.19

CURVE 4 (cont.)

T	$\Delta L/L_0$
2010	1.12
1722	0.79
1283	0.59
1222	0.56
775	0.25
293	0.00*

CURVE 5

T	$\Delta L/L_0$
293	0.00*
517	0.10
782	0.15
1192	0.26
1210	0.27
1463	0.39
1727	0.49
1891	0.52
2027	0.65

CURVE 5 (cont.)

T	$\Delta L/L_0$
2174	0.93
2277	1.40
2333	1.76
2480	1.96

CURVE 6

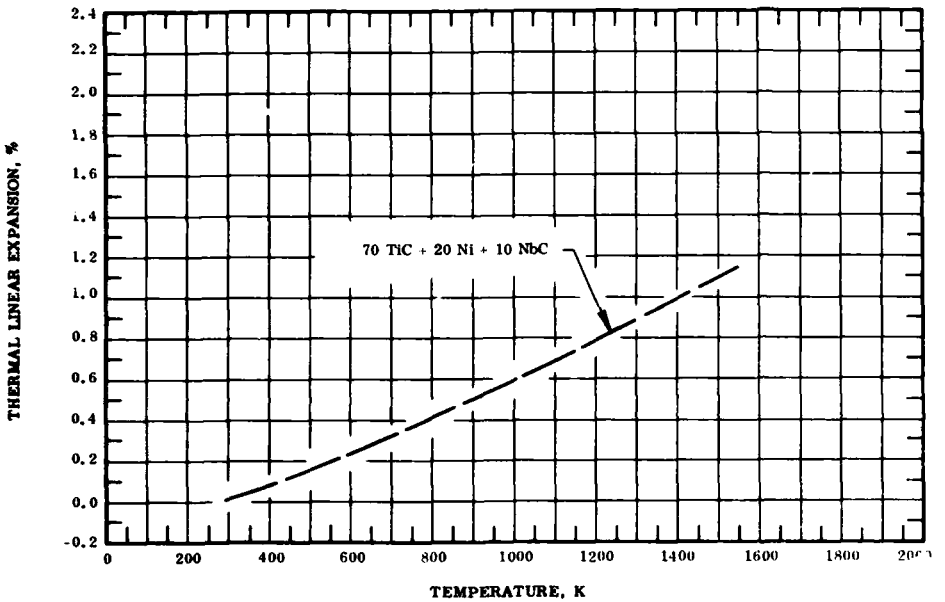
T	$\Delta L/L_0$
2480	0.88
2394	0.75
2230	0.39
2099	0.36
1949	0.23
1783	0.23
1616	0.51
1394	0.46
1185	0.33
1109	0.28
834	0.11

CURVE 6 (cont.)

T	$\Delta L/L_0$
293	0.00*

* Not shown in figure.

FIGURE AND TABLE NO. 356R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF TITANIUM CARBIDE + NICKEL + ΣX_i TiC + Ni + ΣX_i



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_o$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_o$	α
293	0.000	6.8
400	0.076	7.3
500	0.148	7.7
600	0.228	8.1
700	0.312	8.4
800	0.400	8.8
900	0.486	9.1
1000	0.581	9.5
1100	0.677	9.8
1200	0.777	10.1
1300	0.880	10.4
1400	0.984	10.7
1500	1.092	10.9
1550	1.147	11.1

REMARKS

The provisional values for 70TiC + 20Ni + 10NbC cermet are based on the data of Curve 2 and are considered accurate to within ±7%. An addition of about ±5% Nickel increases the thermal expansion values by about 10% (Curve 4). These values are represented approximately by the following equation:

$$\Delta L/L_o = -0.182 + 5.536 \times 10^{-4}\, T + 2.316 \times 10^{-7}\, T^2 - 2.298 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

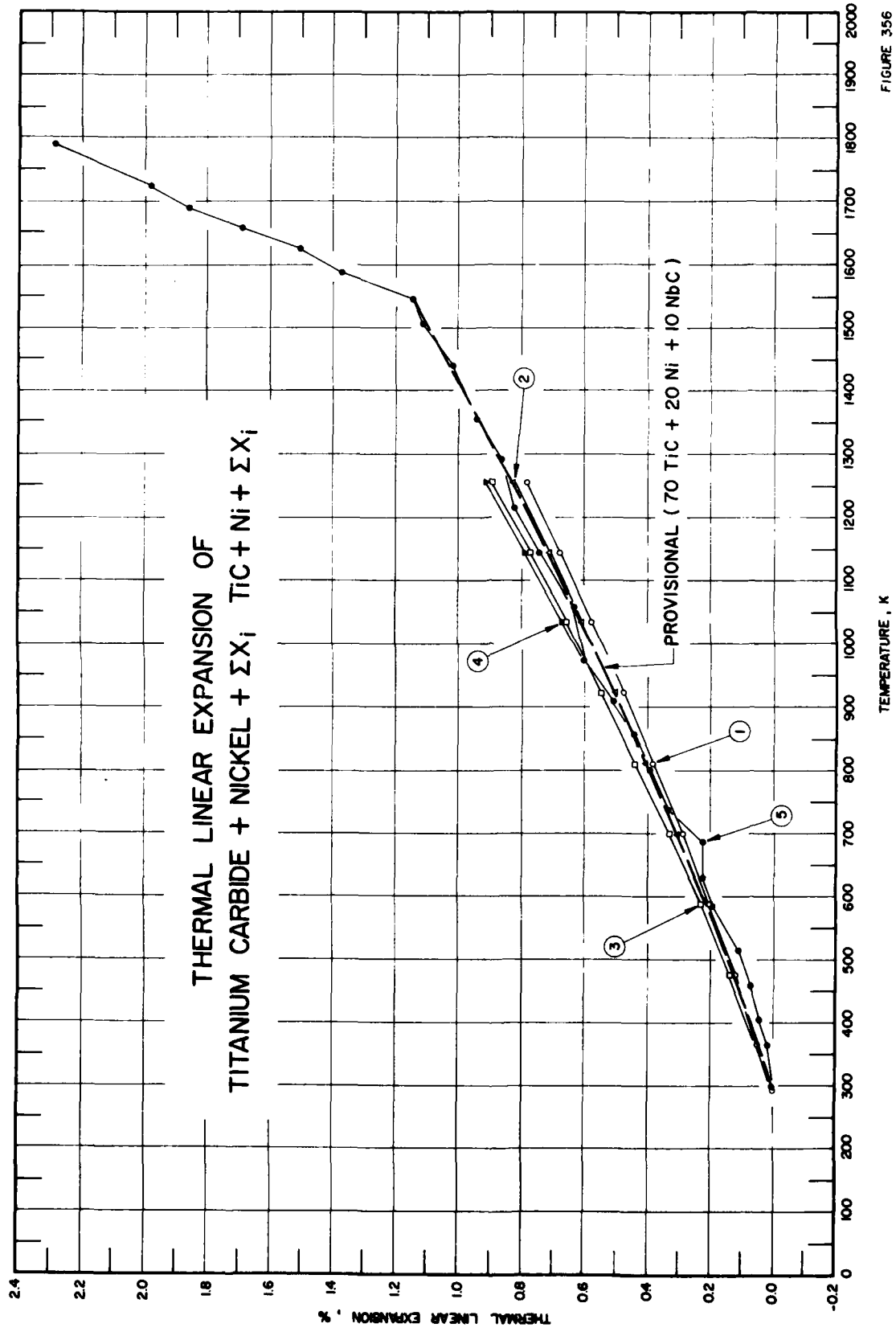

THERMAL LINEAR EXPANSION OF
TITANIUM CARBIDE + NICKEL + ΣXi TiC + Ni + ΣXi
PROVISIONAL (70 TiC + 20 Ni + 10 NbC)
1
2
3
4
5
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIGURE 356

SPECIFICATION TABLE 356. THERMAL LINEAR EXPANSION OF TITANIUM CARBIDE + NICKEL + ΣX_i TiC + Ni + ΣX_i

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1012	Harrington, S.C. and Rowe, G.H.	1963	L	293-1255	K 150 A	80 TiC, 10 Ni, 10 Nb (TaTi)C; dimension 4 mm diameter; 50 mm long; Nb(TaTi)C added as a solid solution of NbC, TaC, and TiC containing about 90% NbC; heating rate at about 1.67 C per minute gradually increased to 1.67 C per minute in vacuum; no permanent change in length, density 5.82 g cm^{-3}.
2	1012	Harrington, S.C. and Rowe, G.H.	1963	L	293-1255	K 151 A	Similar to the above specimen except 70 TiC, 20 Ni, 10 Nb (TaTi)C; density 5.64 g cm^{-3}.
3	1012	Harrington, S.C. and Rowe, G.H.	1963	L	293-1255	K 162 B	Similar to the above specimen except 64 TiC, 25 Ni, 5 Mo, 6 Nb (TaTi)C; density 6.07 g cm^{-3}.
4	1012	Harrington, S.C. and Rowe, G.H.	1963	L	293-1255	K 152 B	Similar to the above specimen except 64 TiC, 30 Ni, 6 Nb (TaTi)C; density 5.93 g cm^{-3}.
5	895	Fieldhouse, I.B. and Lang, J.I.	1961		299-1790	Kennametal K 161 B	72 TiC, 16.7 Ni, 6 Nb(TaTi)C; 3.3 Mo; density 5.66 g cm^{-3}.

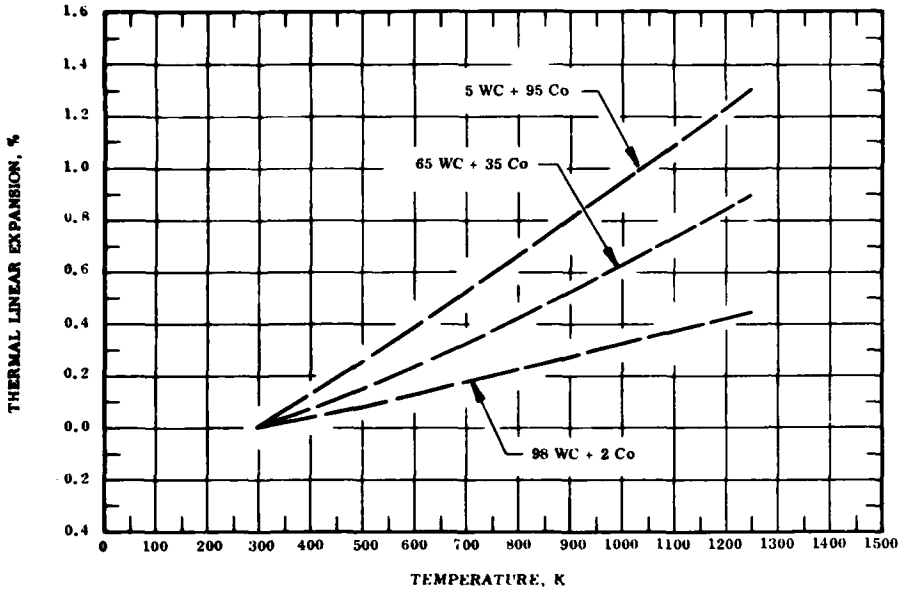
DATA TABLE 356. THERMAL LINEAR EXPANSION OF TITANIUM CARBIDE + NICKEL + ΣX_i TiC + Ni + ΣX_i

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
366	0.052
477	0.122
588	0.205
699	0.291
810	0.384
922	0.480
1033	0.580
1144	0.681
1255	0.785
CURVE 2	
293	0.000*
366	0.053*
477	0.130*
588	0.217*
699	0.308
810	0.406
922	0.503
1033	0.607
1144	0.715
1255	0.826
CURVE 3	
293	0.000*
366	0.054*
477	0.139
588	0.235
699	0.333
810	0.442
922	0.549
1033	0.659
1144	0.776
1255	0.897
CURVE 4	
293	0.000*
366	0.054*
477	0.139*
588	0.235*
699	0.336*
810	0.445*
922	0.556*
1033	0.670
1144	0.791
1255	0.914
CURVE 5	
299	0.002
363	0.019
405	0.043
459	0.074
515	0.113
574	0.198
629	0.224
687	0.227
738	0.338
801	0.396
857	0.445
909	0.510
972	0.602
1059	0.635
1144	0.745
1214	0.825
1291	0.864
1354	0.947
1440	1.020
1506	1.117
1547	1.150
1588	1.373
1625	1.503
1658	1.690
1689	1.859
1724	1.979
1790	2.284

* Not shown in figure.

FIGURE AND TABLE NO. 357R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF TUNGSTEN CARBILE + COBALT WC + Co



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	5 WC +95 Co		65 WC +35 Co		98 WC +2 Co	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	12.0	0.000	6.5	0.000	4.2
400	0.130	12.5	0.075	7.5	0.044	4.4
500	0.255	12.9	0.155	8.2	0.090	4.5
600	0.389	13.3	0.240	8.9	0.135	4.6
700	0.525	13.7	0.332	9.5	0.181	4.6
800	0.662	14.0	0.430	9.9	0.228	4.7
900	0.803	14.2	0.530	10.3	0.274	4.7
1000	0.945	14.4	0.635	10.5	0.320	4.8
1100	1.091	14.6	0.740	10.7	0.365	4.9
1200	1.239	14.6	0.847	10.7	0.411	4.9
1250	1.313	14.6	0.900	10.7	0.433	4.9

REMARKS

The provisional values for the various compositions of WC + Co cerment are based on the selected experimental data. These values are considered accurate to within ±7% and are represented approximately by the following equations:

5 WC +95 Co: $\Delta L/L_0 = -0.326 + 1.026 \times 10^{-3}\ T + 3.258 \times 10^{-7}\ T^2 - 7.900 \times 10^{-11}\ T^3$

65 WC +35 Co: $\Delta L/L_0 = -0.147 + 3.332 \times 10^{-4}\ T + 6.237 \times 10^{-7}\ T^2 - 1.759 \times 10^{-10}\ T^3$

98 WC + 2 Co: $\Delta L/L_0 = -0.116 + 3.628 \times 10^{-4}\ T + 1.208 \times 10^{-7}\ T^2 - 4.783 \times 10^{-11}\ T^3$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equations and are considered accurate to about ±10%.

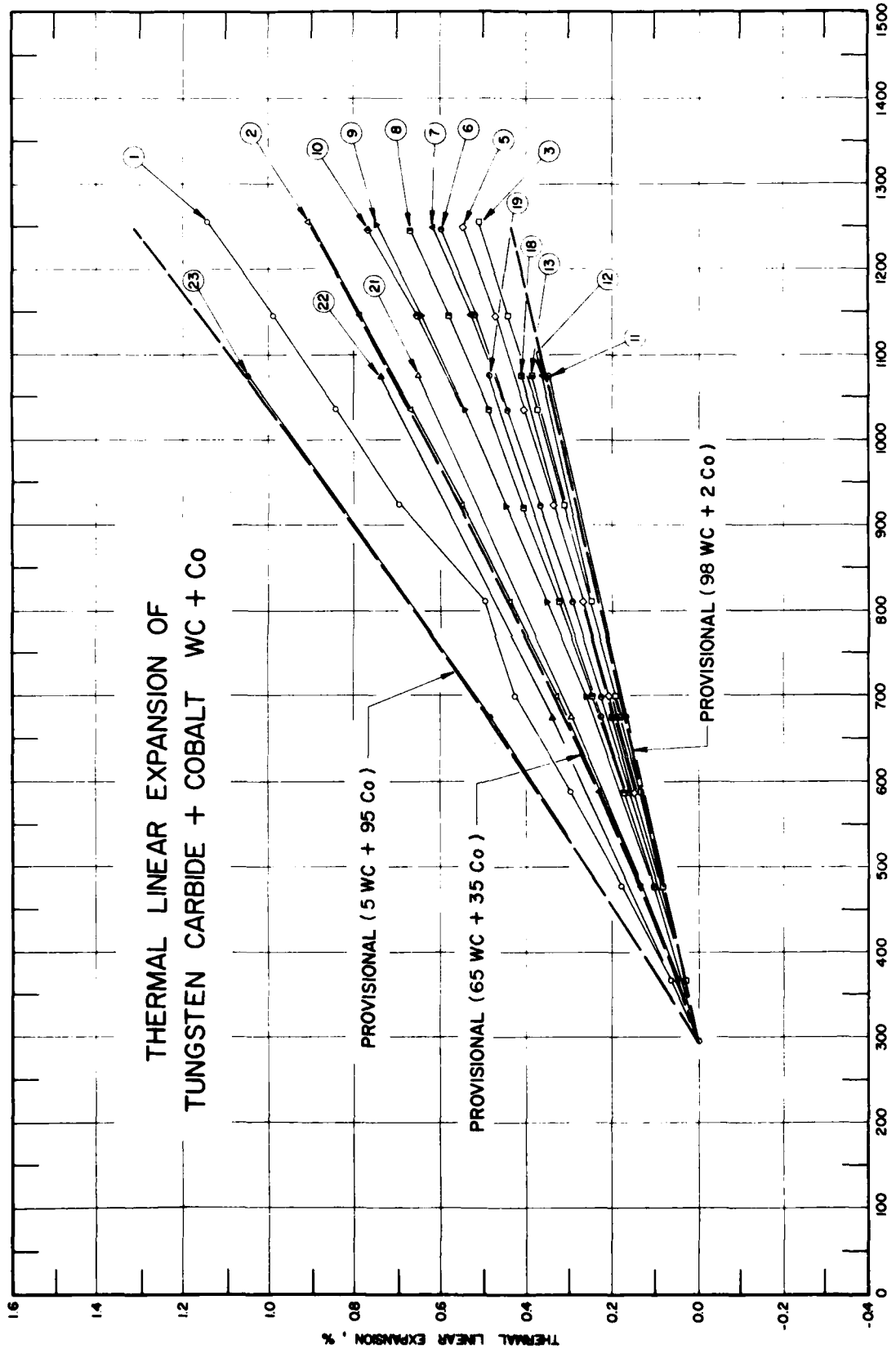

THERMAL LINEAR EXPANSION OF
TUNGSTEN CARBIDE + COBALT WC + Co
PROVISIONAL (5 WC + 95 Co)
PROVISIONAL (65 WC + 35 Co)
PROVISIONAL (98 WC + 2 Co)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-.04
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1
2
3
5
6
7
8
9
10
11
12
13
18
19
21
22
23

FIGURE 357

SPECIFICATION TABLE 357. THERMAL LINEAR EXPANSION OF TUNGSTEN CARBIDE + COBALT WC + Co

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1017	Harrington, L.C. and Rowe, G.H.	1963		293-1225		40 WC, 60 Co; dimension: 4 mm diameter, 50 mm long, finished machined specimen purchased from Kennametal, Inc.; specimen heated in vacuum at the rate of about 1.67 C per minute and increased to 2.78 C per minute at the end of heating; no significant permanent change in length observed after test; density 10.67 g cm^{-3}.
2	1017	Harrington, L.C. and Rowe, G.H.	1963		293-1255		Similar to the above specimen except 65 WC, 35 Co; dimensions: 4 mm diameter, 50 mm long; density 12.22 g cm^{-3}.
3	1017	Harrington, L.C. and Rowe, G.H.	1963		293-1255	Kennametal K-11	Similar to the above specimen except 92.5 W, 6.0 C, 2.5 Co; dimensions: 4 mm diameter, 50 mm long; density 15.2 g cm^{-3}.
4*	1017	Harrington, L.C. and Rowe, G.H.	1963		293-1255	Kennametal K-8	Similar to the above specimen except 90.3 W. 5.9 C, 3.5 Co, 0.3 Ta; dimension 4 mm diameter, 50 mm long; density 15.10 g cm^{-3}.
5	1017	Harrington, L.C. and Rowe, G.H.	1963		293-1249	Kennametal K-96	Similar to the above specimen except 86.3 W, 5.8 C, 5.75 Co, 1.8 Ta, 0.3 Nb; dimensions: 4 mm diameter, 50 mm long; density 14.93 g cm^{-3}.
6	1017	Harrington, L.C. and Rowe, G.H.	1963		293-1247	Kennametal K-95	Similar to the above specimen except 85.6 W, 8.75 Co, 5.6 C, 0.6 Ta, 0.3 Nb; dimensions: 4 mm diameter, 50 mm long; density 14.49 g cm^{-3}.
7	1017	Harrington, L.C. and Rowe, G.H.	1963		293-1249	Kennametal K-94	Similar to the above specimen except 80.6 W, 11.78 Co, 5.4 C, 1.4 Ta, 0.3 Nb; dimensions: 4 mm diameter, 50 mm long; density 14.29 g cm^{-3}.
8	1017	Harrington, L.C. and Rowe, G.H.	1963		293-1244	Kennametal K-92	Similar to the above specimen except 77 W, 16 Co, 5.1 C, 1.6 Ta, 0.3 Nb; dimensions: 4 mm diameter, 50 mm long; density 13.86 g cm^{-3}.
9	1017	Harrington, L.C. and Rowe, G.H.	1963		293-1252	Kennametal K-91	Similar to the above specimen except 71.7 W, 20 Co, 4.7 C, 2.7 Ta, 0.9 Nb; dimensions: 4 mm diameter, 50 mm long; density 13.34 g cm^{-3}.
10	1017	Harrington, L.C. and Rowe, G.H.	1963		293-1244	Kennametal K-90	Similar to the above specimen except 65.6 W, 25 C, 4.4 C, 3.0 Ta, 1.6 Nb; dimensions: 4 mm diameter, 50 mm long; density 13.04 g cm^{-3}.
11	662	Tumanov, V.I., Funke, V.F., Baskin, M.L., and Novikova, T.A.	1964		293-1073		98 WC and 2 Co; mean particle size of WC 2.7 μ.
12	662	Tumanov, V.I., et al.	1964		293-1073		96 WC and 4 Co; mean particle size of WC 2.7 μ.
13	662	Tumanov, V.I., et al.	1964		293-1073		94 WC and 6 Co; mean particle size of WC 1.7 μ.
14*	662	Tumanov, V.I., et al.	1964		293-1073		94 WC and 6 Co; mean particle size of WC 2.3 μ.
15*	662	Tumanov, V.I., et al.	1964		293-1073		94 WC and 6 Co; mean particle size of WC 2.7 μ.
16*	662	Tumanov, V.I., et al.	1964		293-1073		94 WC and 6 Co; mean particle size of WC 3.7 μ.
17*	662	Tumanov, V.I., et al.	1964		293-1073		92 WC and 8 Co; mean particle size of WC 2.7 μ.
18	662	Tumanov, V.I., et al.	1964		293-1073		90 WC and 10 Co; mean particle size of WC, 2.7 μ.
19	662	Tumanov, V.I., et al.	1964		293-1073		88 WC and 12 Co; mean particle size of WC, 2.7 μ.
20	662	Tumanov, V.I., et al.	1964		293-1073		85 WC and 15 Co; mean particle size of WC, 2.7 μ.
21	662	Tumanov, V.I., et al.	1964		293-1073		70 WC and 30 Co; mean particle size of WC, 2.7 μ.
22	662	Tumanov, V.I., et al.	1964		293-1073		50 WC and 50 Co; mean particle size of WC, 2.7 μ.
23	662	Tumanov, V.I., et al.	1964		293-1073		5 WC and 95 Co; mean particle size of WC, 2.7 μ.

* Not shown in figure.

DATA TABLE 357. THERMAL LINEAR EXPANSION OF TUNGSTEN CARBIDE - COBALT WC + Co

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
293	0.000
366	0.064
477	0.179
588	0.300
699	0.425
810	0.500
922	0.700
1033	0.844
1144	0.990
1255	1.142

CURVE 2

T	$\Delta L/L_0$
293	0.000*
366	0.050
477	0.137
588	0.231
699	0.331
810	0.440
922	0.551
1033	0.671
1144	0.790
1255	0.912

CURVE 3

T	$\Delta L/L_0$
293	0.000*
366	0.032
477	0.084
588	0.137
699	0.195
810	0.252
922	0.315
1033	0.378
1144	0.445
1255	0.513

CURVE 4*

T	$\Delta L/L_0$
293	0.000
366	0.032
477	0.084
588	0.134
699	0.198
810	0.258
922	0.320

CURVE 4 (cont.)*

T	$\Delta L/L_0$
1033	0.385
1144	0.452
1255	0.520

CURVE 5

T	$\Delta L/L_0$
293	0.000*
366	0.038*
477	0.090*
588	0.148
699	0.210
810	0.272
922	0.340
1033	0.407
1144	0.477
1249	0.550

CURVE 6

T	$\Delta L/L_0$
293	0.000*
366	0.038*
477	0.092*
588	0.159
699	0.228
810	0.297
922	0.370
1033	0.443
1144	0.521
1247	0.600

CURVE 7

T	$\Delta L/L_0$
293	0.000*
366	0.038*
477	0.092*
588	0.159*
699	0.228*
810	0.298*
922	0.376*
1033	0.453*
1144	0.534
1249	0.620

CURVE 8

T	$\Delta L/L_0$
293	0.000*
366	0.040*
477	0.103
588	0.174
699	0.248
810	0.324
922	0.408
1033	0.492
1144	0.581
1244	0.672

CURVE 9

T	$\Delta L/L_0$
293	0.000*
366	0.040*
477	0.110*
588	0.181*
699	0.269
810	0.355
922	0.450
1033	0.544
1144	0.643
1252	0.751

CURVE 10

T	$\Delta L/L_0$
293	0.000*
366	0.040*
477	0.110*
588	0.181*
699	0.269*
810	0.355*
922	0.451*
1033	0.551*
1144	0.659
1244	0.772

CURVE 11

T	$\Delta L/L_0$
293	0.000*
673	0.171
1073	0.351

CURVE 12

T	$\Delta L/L_0$
293	0.000*
673	0.194
1073	0.366

CURVE 13

T	$\Delta L/L_0$
293	0.000*
673	0.182
1073	0.390

CURVE 14*

T	$\Delta L/L_0$
293	0.000
673	0.186
1073	0.398

CURVE 15*

T	$\Delta L/L_0$
298	0.000
673	0.186
1073	0.390

CURVE 16*

T	$\Delta L/L_0$
293	0.000
673	0.182
1073	0.390

CURVE 17*

T	$\Delta L/L_0$
293	0.000
673	0.190
1073	0.398

CURVE 18

T	$\Delta L/L_0$
293	0.000*
673	0.201
1073	0.413

CURVE 19

T	$\Delta L/L_0$
293	0.000*
673	0.228
1073	0.491

CURVE 20*

T	$\Delta L/L_0$
293	0.000
673	0.228
1073	0.491

CURVE 21

T	$\Delta L/L_0$
293	0.000*
673	0.300
1073	0.655

CURVE 22

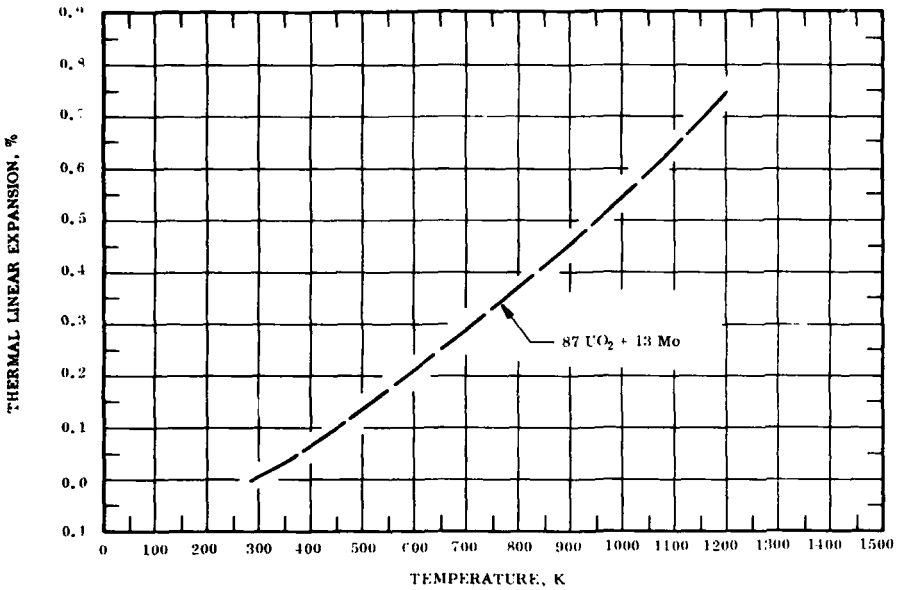
T	$\Delta L/L_0$
293	0.000*
673	0.342
1073	0.741

CURVE 23

T	$\Delta L/L_0$
293	0.000*
673	0.490
1073	1.053

* Not shown in figure.

FIGURE AND TABLE NO. 358R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF URANIUM DIOXIDE + MOLYBDENUM UO_2 + Mo



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	6.2
400	0.070	6.7
500	0.138	7.1
600	0.211	7.5
700	0.288	8.0
800	0.370	8.4
900	0.456	8.9
1000	0.550	9.4
1100	0.642	9.9
1200	0.745	10.4

REMARKS

The provisional values for 87 UO_2 + 13Mo cermet are based on the data of Curve 5 and are considered accurate to within ±10%. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.166 + 5.132 \times 10^{-4}\, T + 1.783 \times 10^{-7}\, T^2 + 2.195 \times 10^{-11}\, T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

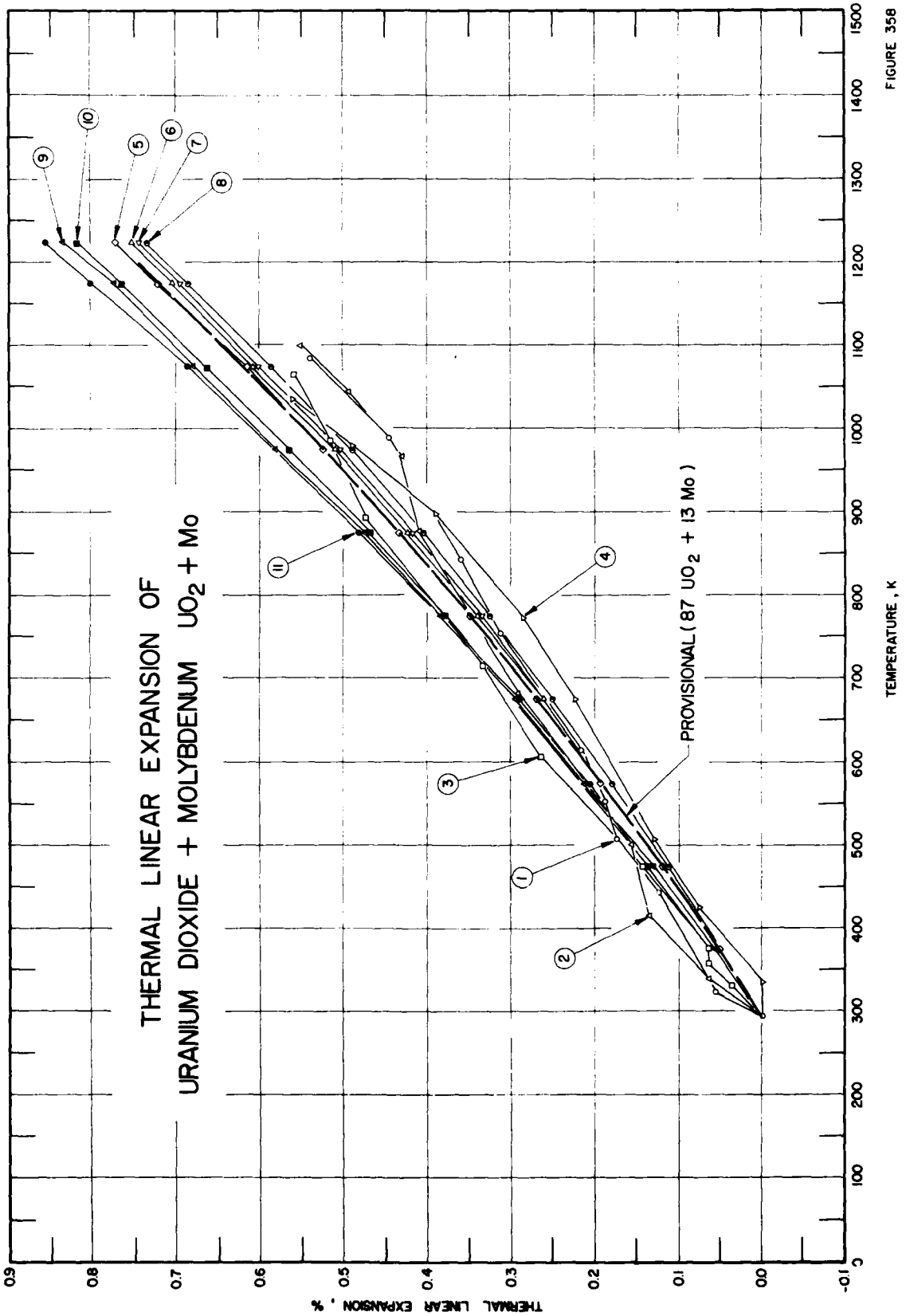

THERMAL LINEAR EXPANSION OF
URANIUM DIOXIDE + MOLYBDENUM UO2 + Mo
PROVISIONAL (87 UO2 + 13 Mo)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1
2
3
4
5
6
7
8
9
10
11

FIGURE 358

SPECIFICATION TABLE 358. THERMAL LINEAR EXPANSION OF URANIUM DIOXIDE + MOLYBDENUM UO_2 + Mo

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1019	Collins, J.F. and Flagella, P.N.	1967	T	293-1083	A-1	Specimen as fabricated; 61.669 UO_2, 38.337 Mo (Mo-60 vol. percent UO_2), prepared by GE-NMPO Camcoat process, using Mo powder of 0.8 μm particle size, chemical analysis < 0.1 N, < 0.5 Cr, < 0.01 each of Al, Fe, and Si, 0.005 Mn, < 0.001 each of Ca, Cu, and Mg; sintered in a W filament furnace; dimensions: 2.0012 in. length, 0.3752 in. diameter, centerless ground to size, measured in helium before and after 21 thermal cycles from 478 to 811 K; approximately 12 min. for both heating and cooling between room temperature and 1089 K.
2	1019	Collins, J.F. and Flagella, P.N.	1967	T	293-1100	A-1	The above specimen; expansion measured after cyclic test.
3	1019	Collins, J.F. and Flagella, P.N.	1967	T	293-1064	A-1	Similar to the above; specimen as fabricated; dimensions: 1.9998 in. long and 0.3749 in. diameter.
4	1019	Collins, J.F. and Flagella, P.N.	1967	T	293-1035	A-1	The above specimen; expansion measured after cyclic test.
5	1018	Paprocki, S.J., Keller, D.L., Cunningham, G.W., and Kizer, D.E.	1960		293-1223	TC-82	UO_2 + 30 vol. % Mo ≈ 86.79 UO_2 + 13.21 Mo; gas pressure handed 70 vol. % - 100 + 140 mesh hydrothermal UO_2 particles and -325 mesh Mo at 1533 K and at 10,000 psi of helium gas pressure for 3 hr; maximum heating rate 3 C per minute; first thermal cycle; 91.7 theoretical density; measured in a vacuum of approximately 5 x 10^{-5} mm Hg; reported error < 2%.
6	1018	Paprocki, S.J., et al.	1960		1223-293	TC-82	The above specimen; expansion measured with decreasing temperatures at a rate of 3 C per minute.
7	1018	Paprocki, S.J., et al.	1960		293-1223	TC-82	The above specimen; second thermal cycle; expansion measured with increasing temperature.
8	1018	Paprocki, S.J., et al.	1960		1223-293	TC-82	The above specimen; expansion measured with decreasing temperature.
9	1018	Paprocki, S.J., et al.	1960		1223-293	TC-105	UO_2 + 20 vol. % Mo ≈ 91.88 UO_2 + 8.22 Mo; similar to the above specimen except 80 vol. % spherical UO_2 particles and pressure bonded at 1561 K; theoretical density 94.9 g cm^{-3}.
10	1018	Paprocki, S.J., et al.	1960		1223-293	TC-105	The above specimen; expansion measured with decreasing temperature.
11	1018	Paprocki, S.J., et al.	1960		293-1223	TC-105	The above specimen; second thermal cycle; expansion measured with increasing temperature; reported error < 2%.
12*	1018	Paprocki, S.J., et al.	1960		1223-293	TC-105	The above specimen; expansion measured with decreasing temperature.

* Not shown in figure.

DATA TABLE 358. THERMAL LINEAR EXPANSION OF URANIUM DIOXIDE + MOLYBDENUM UO_2 + Mo

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
293	0.000
322	0.057
442	0.125
508	0.174
551	0.188
613	0.217
762	0.312
842	0.361
988	0.447
1083	0.540

CURVE 2

T	$\Delta L/L_0$
293	0.000*
338	0.066
415	0.137
500	0.157
681	0.292
877	0.410
966	0.431
1043	0.494
1100	0.552

CURVE 3

T	$\Delta L/L_0$
293	0.000*
329	0.038
354	0.066
375	0.066
473	0.144
605	0.266
714	0.334
892	0.474
983	0.516
1064	0.559

CURVE 4

T	$\Delta L/L_0$
293	0.000*
333	0.000
424	0.076
507	0.130
683	0.223
772	0.287
898	0.390

CURVE 4 (cont.)

T	$\Delta L/L_0$
979	0.489
1035	0.561

CURVE 5

T	$\Delta L/L_0$
293	0.000*
373	0.052
473	0.121
573	0.193
673	0.270
773	0.350
873	0.435
973	0.524
1073	0.616
1173	0.722
1223	0.772

CURVE 6

T	$\Delta L/L_0$
1223	0.753
1173	0.704
1073	0.608
973	0.510
873	0.423
773	0.341
673	0.262
573	0.190*
473	0.121*
373	0.053*
293	0.000*

CURVE 7

T	$\Delta L/L_0$
293	0.000*
373	0.053*
473	0.121*
573	0.190*
673	0.262*
773	0.336
873	0.418
973	0.503
1073	0.601
1173	0.695
1223	0.744

CURVE 8

T	$\Delta L/L_0$
1223	0.735
1173	0.686
1073	0.585
973	0.489
873	0.406
773	0.326
673	0.251
573	0.179
473	0.113
373	0.050*
293	0.000*

CURVE 9

T	$\Delta L/L_0$
293	0.000*
373	0.058
473	0.131
573	0.213
673	0.296
773	0.384
873	0.476
973	0.571
1073	0.679
1173	0.774
1223	0.837

CURVE 10

T	$\Delta L/L_0$
1223	0.818
1173	0.766
1073	0.663
973	0.564
873	0.469
773	0.379
673	0.296*
573	0.216*
473	0.137
373	0.061*
293	0.000*

CURVE 11

T	$\Delta L/L_0$
293	0.000*
373	0.054*
473	0.126*

CURVE 11 (cont.)

T	$\Delta L/L_0$
573	0.204
673	0.289
773	0.379*
873	0.481
973	0.578*
1073	0.686
1173	0.801
1223	0.856

CURVE 12*

T	$\Delta L/L_0$
1223	0.837
1173	0.783
1073	0.679
973	0.578
873	0.481
773	0.389
673	0.300
573	0.216
473	0.135
373	0.058
293	0.000

* Not shown in figure.

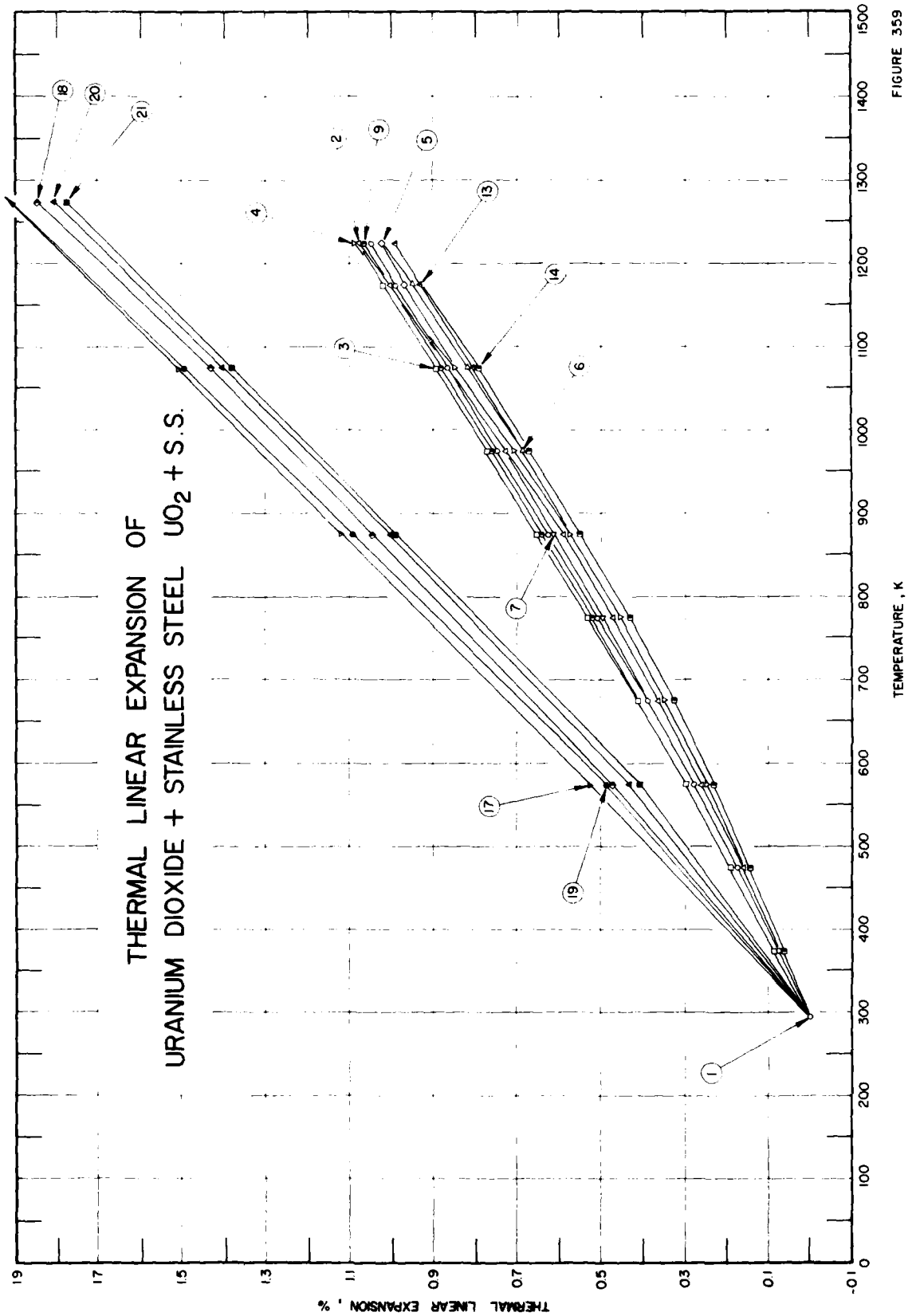

THERMAL LINEAR EXPANSION OF
URANIUM DIOXIDE + STAINLESS STEEL UO_2 + S.S.
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
-0.1
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

FIGURE 359

SPECIFICATION TABLE 359. THERMAL LINEAR EXPANSION OF URANIUM DIOXIDE + STAINLESS STEEL UO_2 + S.S.

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1018	Paprocki, S.J., Keller, D.L., Cunningham, G.W., and Kizer, D.E.	1960		293-1223	TC-81	Specimen of 30 vol.% stainless steel; gas pressure bonded 70 vol.% -100 + 140 mesh hydrothermal UO_2 particles and -325 mesh 302 B stainless steel at 1533 K and at 10,000 psi of helium gas pressure for 3 hr; maximum heating rate 3 C per minute; second thermal cycle; measured in a vacuum of approximately 5×10^{-5} mm Hg; 97% theoretical density; reported error < 2%.
2	1018	Paprocki, S.J., et al.	1960		1223-293	TC-81	The above specimen; expansion measured with decreasing temperature at a rate of 3 C per minute.
3	1018	Paprocki, S.J., et al.	1960		293-1223	TC-81	The above specimen; third thermal cycle given in increasing temperature.
4	1018	Paprocki, S.J., et al.	1960		1223-293	TC-81	The above specimen; expansion measured with decreasing temperature.
5	1018	Paprocki, S.J., et al.	1960		293-1223	TC-80	Similar to the above specimen except 20 vol.% stainless steel; 80 vol.% hydrothermal UO_2 particles and first thermal cycle; 95.5% theoretical density.
6	1018	Paprocki, S.J., et al.	1960		1223-293	TC-80	The above specimen; expansion measured with decreasing temperature.
7	1018	Paprocki, S.J., et al.	1960		293-1223	TC-80	The above specimen; second thermal cycle; expansion measured with increasing temperature.
8	1018	Paprocki, S.J., et al.	1960		1223-293	TC-80	The above specimen; expansion measured with decreasing temperature.
9	1018	Paprocki, S.J., et al.	1960		293-1223	TC-102	Similar to the above specimen except 98.4 theoretical density.
10	1018	Paprocki, S.J., et al.	1960		1223-293	TC-102	The above specimen; expansion measured with decreasing temperature.
11	1018	Paprocki, S.J., et al.	1960		293-1223	TC-102	The above specimen; second thermal cycle; expansion measured with increasing temperature.
12	1018	Paprocki, S.J., et al.	1960		1223-293	TC-102	The above specimen; expansion measured with decreasing temperature.
13	1018	Paprocki, S.J., et al.	1960		293-1223	TC-103	Similar to the above specimen except 20 vol.% stainless steel; 80 vol.% spherical UO_2 particles; 97.2 theoretical density.
14	1018	Paprocki, S.J., et al.	1960		1223-293	TC-103	The above specimen; expansion measured with decreasing temperature.
15	1018	Paprocki, S.J., et al.	1960		293-1223	TC-103	The above specimen; second thermal cycle; expansion measured with increasing temperature.
16	1018	Paprocki, S.J., et al.	1960		1223-293	TC-103	The above specimen; expansion measured with decreasing temperature.
17	1020	Arthur, G. and Coulson, J.A.	1964		293-1273		24.5 vol.% UO_2; spherical particles of UO_2 (-72 to +100 mesh) and 316 L stainless steel (-300 mesh) mixed 30 min. by tumbling in bottle; 1% water added, placed in rubber bag and hydrastatically pressed at 20 psi; sintered 1 hr in hydrogen atmosphere at 1623 K; ground to shape; sealed and evacuated in steel tube, densified by hot rotary swaging at 1273 K to 40% reduction in area; ground to size and annealed in hydrogen at 1473 K.
18	1020	Arthur, G. and Coulson, J.A.	1964		293-1273		Similar to the above specimen except 50 vol.% UO_2.
19	1020	Arthur, G. and Coulson, J.A.	1964		293-1273		Similar to the above specimen except 24.5 vol.% irregularly shaped particles of electrolytic UO_2 bonded with 347 stainless steel.
20	1020	Arthur, G. and Coulson, J.A.	1964		293-1273		Similar to the above specimen except 50 vol.% UO_2.
21	1020	Arthur, G. and Coulson, J.A.	1964		293-1273		Similar to the above specimen except 63.5 vol.% UO_2.

DATA TABLE 359. THERMAL LINEAR EXPANSION OF URANIUM DIOXIDE + STAINLESS STEEL UO_2 + S.S.

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
373	0.077
473	0.175
573	0.280
673	0.391
773	0.509
873	0.626
973	0.748
1073	0.866
1173	0.994
1223	1.051
CURVE 2	
1223	1.079
1173	1.003
1073	0.866*
973	0.728
873	0.592
773	0.475
673	0.365
573	0.260
473	0.160
373	0.070*
293	0.000*
CURVE 3	
293	0.000*
373	0.083
473	0.189
573	0.300
673	0.414
773	0.533
873	0.655
973	0.775
1073	0.897
1173	1.021
1223	1.079*
CURVE 4	
1223	1.088
1173	1.003*
1073	0.850

T	$\Delta L/L_0$
CURVE 4 (cont.)	
973	0.707
873	0.574
773	0.456
673	0.350
573	0.249
473	0.158*
373	0.070*
293	0.000*
CURVE 5	
293	0.000*
373	0.082*
473	0.184*
573	0.288*
673	0.395*
773	0.509*
873	0.621*
973	0.734*
1073	0.850*
1173	0.968
1223	1.023
CURVE 6	
1223	1.023*
1173	0.950
1073	0.819
973	0.687
873	0.568*
773	0.456*
673	0.353*
573	0.255*
473	0.162*
373	0.072*
293	0.000*
CURVE 7	
293	0.000*
373	0.078*
473	0.178*
573	0.280*
673	0.388*
773	0.499

T	$\Delta L/L_0$
CURVE 7 (cont.)	
873	0.615
973	0.728*
1073	0.842*
1173	0.968*
1223	1.042*
CURVE 8*	
1223	1.023
1173	0.959
1073	0.819
973	0.694
873	0.568
773	0.456
673	0.353
573	0.255
473	0.157
373	0.066
293	0.000
CURVE 9	
293	0.000*
373	0.081*
473	0.185*
573	0.294*
673	0.407*
773	0.523
873	0.644
973	0.762
1073	0.881
1173	1.003*
1223	1.070
CURVE 10*	
1223	1.051
1173	0.977
1073	0.842
973	0.714
873	0.586
773	0.475
673	0.369
573	0.266
473	0.169

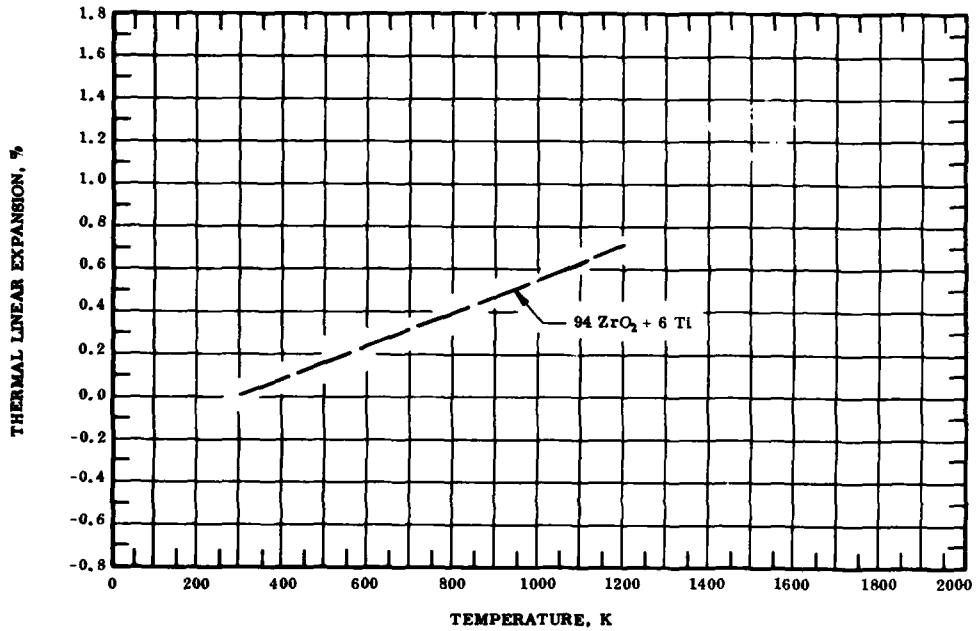
T	$\Delta L/L_0$
CURVE 10 (cont.)*	
373	0.074
293	0.000
CURVE 11*	
293	0.000
373	0.081
473	0.182
573	0.288
673	0.399
773	0.514
873	0.638
973	0.755
1073	0.874
1173	0.944
1223	1.051
CURVE 12*	
1223	1.042
1173	0.977
1073	0.842
973	0.714
873	0.586
773	0.470
673	0.365
573	0.263
473	0.166
373	0.074
293	0.000
CURVE 13	
293	0.000*
373	0.068*
473	0.155*
573	0.258*
673	0.361*
773	0.470*
873	0.586*
973	0.694*
1073	0.811
1173	0.933
1223	0.995

T	$\Delta L/L_0$
CURVE 14	
1223	0.995*
1173	0.924*
1073	0.796
973	0.673
873	0.551
773	0.432
673	0.327
573	0.232
473	0.142
373	0.062
293	0.000*
CURVE 15*	
293	0.000
373	0.074
473	0.171
573	0.277
673	0.388
773	0.499
873	0.621
973	0.734
1073	0.850
1173	0.968
1223	1.032
CURVE 16*	
1223	1.032
1173	0.968
1073	0.835
973	0.707
873	0.580
773	0.470
673	0.361
573	0.260
473	0.166
373	0.073
293	0.000
CURVE 17	
293	0.000*
573	0.526
873	1.119

T	$\Delta L/L_0$
CURVE 17 (cont.)	
1073	1.505
1273	1.911
CURVE 18	
293	0.000*
573	0.473
873	1.044
1073	1.435
1273	1.842
CURVE 19	
293	0.000*
573	0.487
873	1.096
1073	1.498
1273	1.911*
CURVE 20	
293	0.000*
573	0.437
873	1.003
1073	1.404
1273	1.803
CURVE 21	
293	0.000*
573	0.409
873	0.992
1073	1.381
1273	1.774

* Not shown in figure.

FIGURE AND TABLE NO. 360R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE + TITANIUM ZrO_2 + Ti



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	8.0
400	0.085	8.0
500	0.163	8.0
600	0.240	8.0
700	0.315	8.0
800	0.392	8.0
900	0.470	8.0
1000	0.545	8.0
1100	0.622	8.0
1200	0.701	8.0

REMARKS

The provisional values for the 94 ZrO_2 + 6 Ti cermet are based on the data of Curves 1 and 7 measured during the heating cycle. No values are given beyond the transition temperature which depends upon the heating and cooling cycle. These values are considered accurate to within ±10% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.242 + 8.578 \times 10^{-4} T - 1.220 \times 10^{-7} T^2 + 5.155 \times 10^{-11} T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

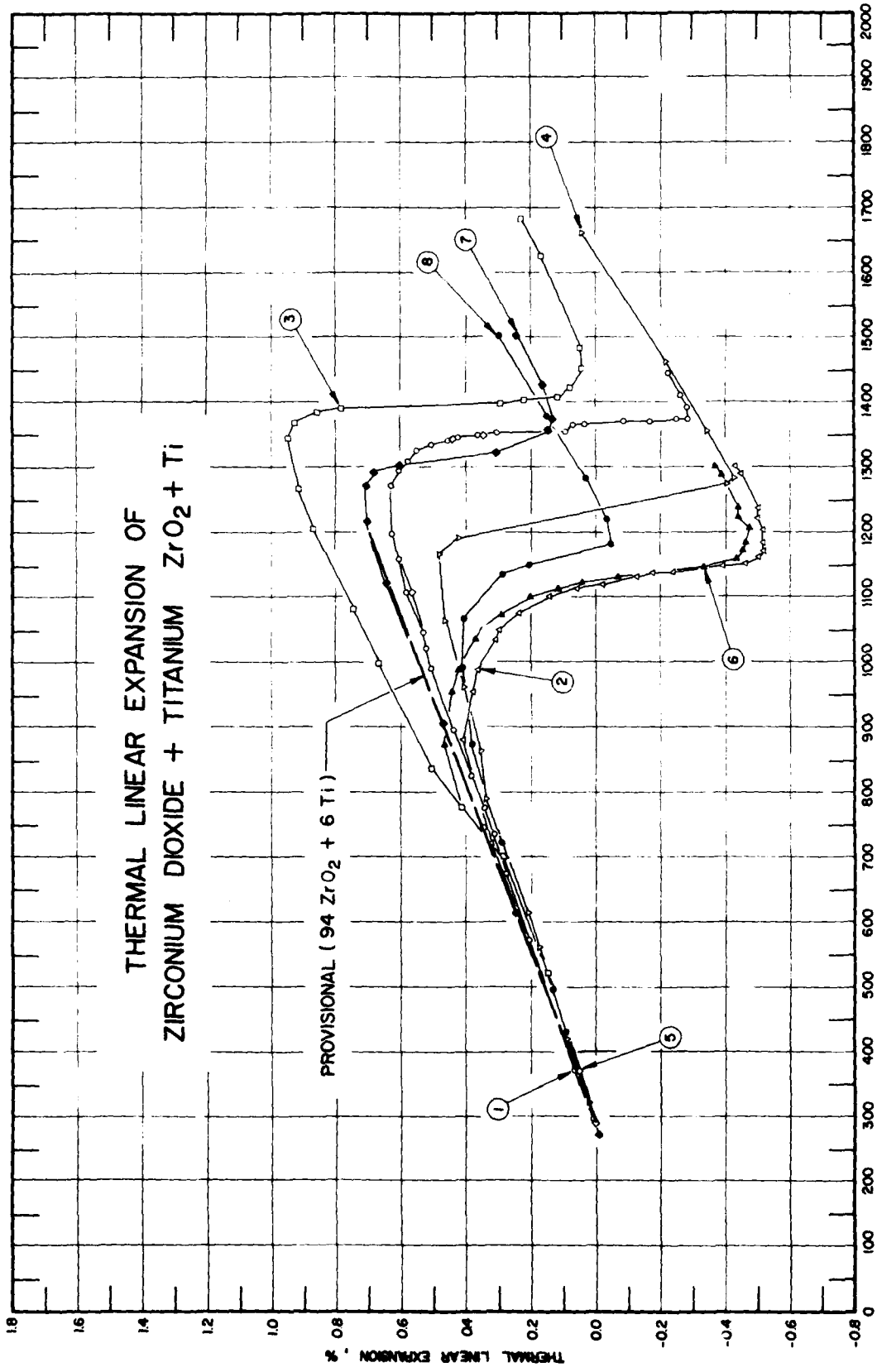

THERMAL LINEAR EXPANSION OF
ZIRCONIUM DIOXIDE + TITANIUM ZrO_2 + Ti
PROVISIONAL (94 ZrO_2 + 6 Ti)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
1
2
3
4
5
6
7
8

FIGURE 360

SPECIFICATION TABLE 360. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE + TITANIUM ZrO_2 + Ti

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1022	Arias, A.	1966	L	300-1449	ZT-15-M	93.58 ZrO_2 (85 mole percent), 6.42 Ti (15 mole percent); prepared by mixing pure zirconia with 15 mole percent titanium; cold-pressing at 10,000 to 20,000 psi, hydrostatically pressing at 46,000 to 50,000 psi, and vacuum-sintered in tungsten boats at 1870 C for 1 hr under pressure of 20.5 μ of Hg; mixture powders milled for 72 hr before consolidated; measured in vacuum with increasing temperature; zero-point correction is 0.006%.
2	1022	Arias, A.	1966	L	1304-723	ZT-15-M	The above specimen; expansion measured with decreasing temperature; zero-point correction is -0.060%.
3	41	Burdick, R.B. and Hoskyns, W.R.	1963	L	299-1685		97.99 ZrO_2 (95 mole percent), 2.01 Ti (5 mole percent); 0.75 in. long, 0.375 square cross-section; formed by cold-pressing, followed by sintering; metal modified zirconia, sintered for 2 hr at 2000 C in a vacuum furnace; cooled to room temperature in 1 hr, heating rate 2.5 C/min.; expansion measured with increasing temperature; zero-point correction 0.004%.
4	41	Burdick, R.B. and Hoskyns, W.R.	1963	L	1664-325		The above specimen; expansion measured with decreasing temperature; zero-point correction is -0.160%.
5	1023	Arias, A.	1964		293-1450	ZT-15-M	15 mole percent Ti; 0.37 wt.% maximum W, Co, C each; dimensions: 3 in. by 0.4 in. by 0.4 in.; milled, cold-pressed, vacuum sintered 1294 K for 1 hr and then ground; density 5.65-5.75 g cm^{-3}; measured in a vacuum of less than 0.5×10^{-6} mm Hg with a heating rate of less than 0.1 C per minute.
6	1023	Arias, A.	1964		1303-293	ZT-15-M	The above specimen; expansion measured with decreasing temperature with a cooling rate of less than 0.1 C per minute.
7	182	Mauer, F.A. and Bolz, L.H.	1959	L	273-1506		93.6 ZrO_2, 6.4 Ti; prepared by Dr. B.C. Weber of Wright Air Development Center in form of tube; specimen fired at 2143 K in vacuo 1.5 hr; expansion measured under vacuum of 10^{-4} mm Hg with increasing temperature; zero-point correction is -0.010%.
8	182	Mauer, F.A. and Bolz, L.H.	1959	L	1506-433		The above specimen; expansion measured with decreasing temperature; zero-point correction is 0.040%.

DATA TABLE 360. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE + TITANIUM ZrO_2 + Ti

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
300	0.006
374	0.066
574	0.206
676	0.280
738	0.317
779	0.343
828	0.383
899	0.440
992	0.506
1023	0.522
1049	0.533
1110	0.583
1162	0.606
1200	0.631
1273	0.635
1299	0.606
1312	0.580
1329	0.554
1338	0.506
1344	0.459
1349	0.428
1351	0.363
1356	0.307
1358	0.097
1369	0.071
1369	0.036
1373	-0.084
1373	-0.165
1378	-0.246
1378	-0.281
1394	-0.281
1412	-0.259
1449	-0.220

CURVE 2

T	$\Delta L/L_0$
1304	-0.428
1291	-0.445
1240	-0.500
1225	-0.499
1208	-0.517
1189	-0.517
1175	-0.517
1166	-0.500
1156	-0.459

CURVE 2 (cont.)

T	$\Delta L/L_0$
1151	-0.391
1141	-0.235
1141	-0.175
1136	-0.126
1123	-0.018
1117	0.060
1104	0.141
1079	0.240
1053	0.297
1038	0.311
990	0.363
958	0.380
883	0.410
723	0.324

CURVE 3

T	$\Delta L/L_0$
299	0.004*
523	0.151
702	0.284
748	0.344
780	0.416
838	0.504
1001	0.668
1083	0.750
1208	0.873
1270	0.920
1347	0.950
1371	0.931
1386	0.861
1392	0.782
1400	0.295
1404	0.222
1411	0.120
1427	0.081
1454	0.046
1488	0.053
1628	0.172
1685	0.235

CURVE 4

T	$\Delta L/L_0$
1664	0.042
1466	-0.212
1360	-0.339

CURVE 4 (cont.)

T	$\Delta L/L_0$
1286	-0.422
1277	-0.401
1194	0.426
1170	0.486
1068	0.467
966	0.406
867	0.355
792	0.340
617	0.212
563	0.178
423	0.088
325	0.022

CURVE 5

T	$\Delta L/L_0$
293	0.000
375	0.058
576	0.201*
678	0.278*
738	0.314*
781	0.339*
829	0.382*
901	0.439*
993	0.501*
1023	0.520*
1049	0.530*
1110	0.574
1163	0.600*
1200	0.625*
1272	0.624*
1299	0.599*
1316	0.575*
1330	0.548*
1340	0.500*
1345	0.445
1348	0.420*
1352	0.351
1354	0.303*
1359	0.085*
1366	0.069*
1369	0.030*
1373	-0.094*
1373	-0.169*
1378	-0.255*
1378	-0.288*

CURVE 5 (cont.)

T	$\Delta L/L_0$
1393	-0.288*
1414	-0.266*
1450	-0.223*

CURVE 6

T	$\Delta L/L_0$
1303	-0.367
1293	-0.385
1240	-0.438
1227	-0.439
1209	-0.472
1189	-0.460
1177	-0.450
1168	-0.442
1163	-0.432*
1155	-0.395*
1148	-0.329
1139	-0.175*
1137	-0.120
1134	-0.065
1125	0.040
1118	0.120
1105	0.202
1077	0.298
1053	0.351
1040	0.373
990	0.430
958	0.446
877	0.470
723	0.380*
293	0.000*

CURVE 7

T	$\Delta L/L_0$
273	-0.010
297	0.004*
616	0.249
909	0.475
1125	0.646
1219	0.704
1273	0.712
1295	0.686
1305	0.609
1327	0.310
1360	0.147

CURVE 7 (cont.)

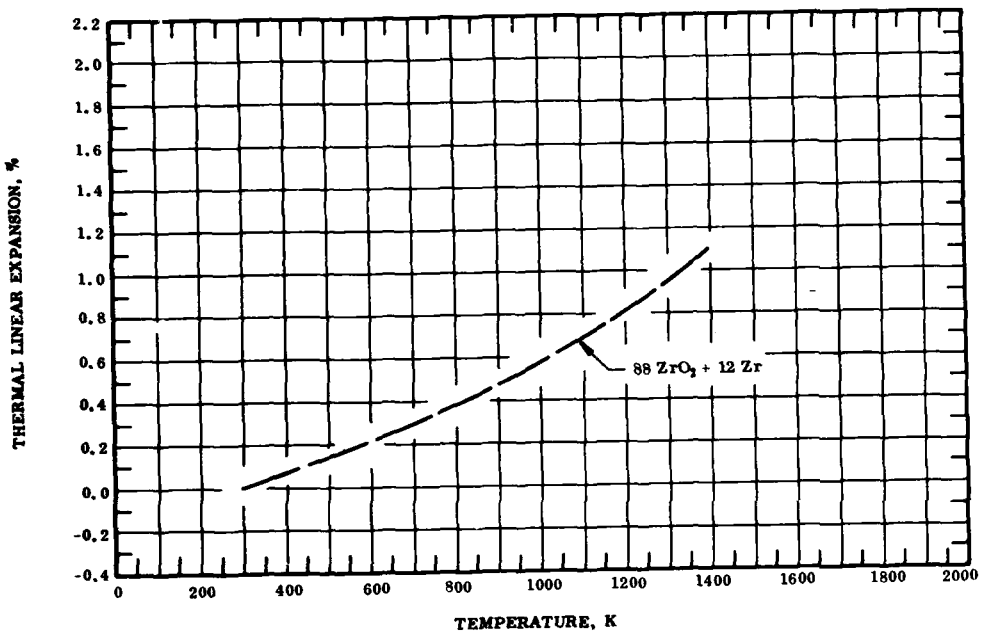
T	$\Delta L/L_0$
1378	0.178
1430	0.164
1506	0.249

CURVE 8

T	$\Delta L/L_0$
1506	0.299
1381	0.154
1285	0.034
1223	-0.037
1185	-0.047
1153	0.206
1139	0.290
1071	0.405
994	0.416
878	0.383
723	0.291
500	0.136
433	0.092

* Not shown in figure.

FIGURE AND TABLE NO. 361R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE + ZIRCONIUM $ZrO_2 + Zr$



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
293	0.000	6.3
400	0.070	6.7
500	0.140	7.1
600	0.212	7.6
700	0.291	8.3
800	0.377	9.0
900	0.470	9.8
1000	0.573	10.6
1100	0.695	11.6
1200	0.810	12.6
1300	0.938	13.8
1400	1.081	15.0

REMARKS

The provisional values are based on the data for heating cycle (Curves 1 and 3). No values are given beyond the transition temperature which depends upon the heating and cooling cycle. These values are considered accurate to within ±10% and are represented approximately by the following equation:

$$\Delta L/L_0 = -0.174 + 5.724 \times 10^{-4}\, T + 3.152 \times 10^{-8}\, T^2 + 1.428 \times 10^{-10}\, T^3$$

The tabulated values for the coefficients of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ±10%.

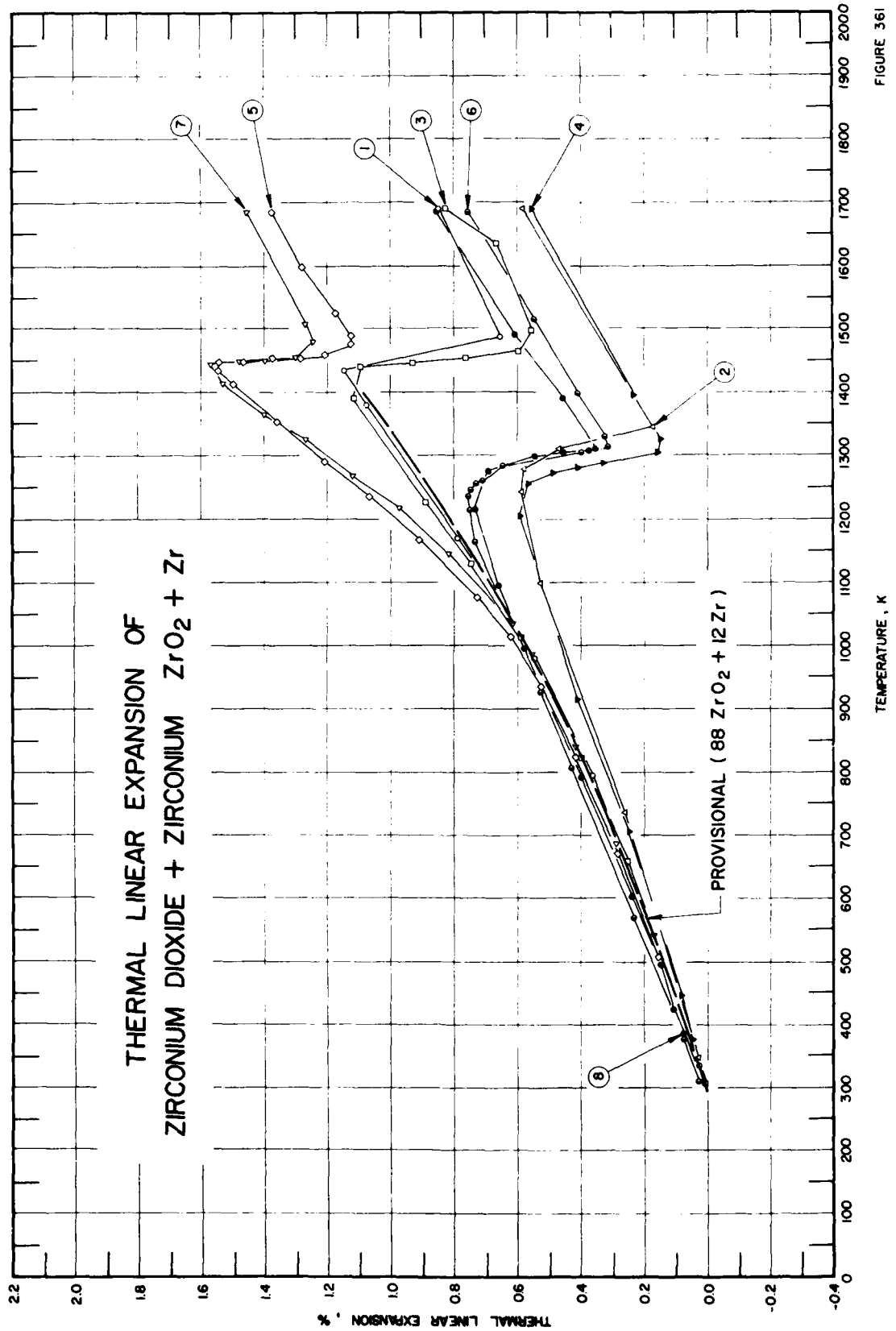

THERMAL LINEAR EXPANSION OF
ZIRCONIUM DIOXIDE + ZIRCONIUM ZrO_2 + Zr
PROVISIONAL (88 ZrO_2 + 12 Zr)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1
2
3
4
5
6
7
8

FIGURE 361

SPECIFICATION TABLE 361. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE + ZIRCONIUM $ZrO_2 + Zr$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	41	Burdick, R. B. and Hoskyns, W. R.	1963	L	333-1689	RUN 110	95.49 ZrO_2 and 4.512 Zr; 0.75 in. long, 0.375 square cross-section, formed by cold-pressing, followed by sintering; metal modified zirconia, sintered for 2 hr at 2000 C in a vacuum furnace, cooled to room temperature in one hour, heating rate 2.5 C/min.; expansion measured with increasing temperature; zero-point correction is 0.029%.
2	41	Burdick, R. B. and Hoskyns, W. R.	1963	L	1689-347	RUN 110	95.49 ZrO_2 and 4.512 Zr; the above specimen, expansion measured with decreasing temperature.
3	41	Burdick, R. B. and Hoskyns, W. R.	1963	L	308-1689	RUN 160	95.49 ZrO_2 and 4.512 Zr; the above specimen; expansion measured with increasing temperature; zero-point correction is 0.004%.
4	41	Burdick, R. B. and Hoskyns, W. R.	1963	L	1689-377	RUN 160	95.49 ZrO_2 and 4.512 Zr; the above specimen; expansion measured with decreasing temperature; zero-point correction is -0.264%.
5	41	Burdick, R. B. and Hoskyns, W. R.	1963	L	305-1684	RUN 139	88.44 ZrO_2 and 11.55 Zr; similar to the above specimen; expansion measured with increasing temperature.
6	41	Burdick, R. B. and Hoskyns, W. R.	1963	L	1684-310	RUN 139	88.44 ZrO_2 and 11.55 Zr; the above specimen; expansion measured with decreasing temperature; zero-point correction is -0.620%.
7	41	Burdick, R. B. and Hoskyns, W. R.	1963	L	346-1685	RUN 140	88.44 ZrO_2 and 11.55 Zr; the above specimen; expansion measured with increasing temperature; zero-point correction 0.006%.
8	41	Burdick, R. B. and Hoskyns, W. R.	1963	L	1685-312	RUN 140	88.44 ZrO_2 and 11.55 Zr; the above specimen; expansion measured with decreasing temperature; zero-point correction is -0.600%.

DATA TABLE 361. THERMAL LINEAR EXPANSION OF ZIRCONIUM DIOXIDE + ZIRCONIUM $ZrO_2 + Zr$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
333	0.029
795	0.362
980	0.543
1170	0.791
1380	1.076
1435	1.143
1488	0.653
1689	0.847
CURVE 2	
1689	0.581
1344	0.174
1311	0.463
1278	0.579
1242	0.583
1099	0.528
735	0.261
347	0.030
CURVE 3	
308	0.011
658	0.256
822	0.398
1012	0.590
1129	0.747
1227	0.891
1389	1.115
1441	1.097
1448	0.932
1454	0.760
1463	0.595
1498	0.551
1634	0.662
1689	0.822
CURVE 4	
1689	0.554
1395	0.233
1327	0.144
1303	0.156
1297	0.242
1289	0.324
CURVE 4 (cont.)	
1281	0.405
1273	0.484
1257	0.563
1206	0.593
916	0.408
705	0.248
447	0.086
377	0.050
CURVE 5	
305	0.009*
507	0.158
670	0.283
824	0.415
935	0.526
1014	0.623
1076	0.730
1168	0.912
1236	1.067
1291	1.207
1353	1.360
1412	1.499
1434	1.543
1449	1.542
1449	1.463
1455	1.375
1455	1.285
1461	1.202
1477	1.129
1489	1.128
1527	1.174
1600	1.279
1684	1.377
CURVE 6	
1684	0.757
1515	0.544
1399	0.405
1329	0.321
1314	0.311
1306	0.397
1299	0.482
1288	0.549
CURVE 6 (cont.)	
1283	0.644
1260	0.708
1255	0.732
1245	0.746
1237	0.756
1213	0.752
1164	0.737
927	0.530
806	0.430
568	0.233
377	0.079
310	0.030
CURVE 7	
346	0.037*
541	0.172
686	0.290
840	0.414
984	0.553
1036	0.616
1147	0.818
1218	0.974
1269	1.119
1327	1.266
1365	1.399
1415	1.532
1447	1.568
1451	1.480
1451	1.396
1457	1.298
1479	1.242
1509	1.268
1685	1.454
CURVE 8	
1685	0.848
1491	0.604
1391	0.456
1312	0.352
1309	0.372
1305	0.456
1300	0.542
1274	0.693
CURVE 8 (cont.)	
1243	0.745*
1215	0.735
1095	0.660
995	0.581
792	0.399
601	0.240
497	0.151
423	0.109
385	0.080
312	0.035*

* Not shown in figure.

SPECIFICATION TABLE 362. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERMETS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	1011	Greenspan, J.	1953		293-1073	BeO + Be Mo	Beryllium oxide + beryllium + molybdenum; hot-pressed -60 mesh high-fired beryllia, 15-25 μ beryllium, and molybdenum (reduced on beryllia from molybdenum trioxide in hydrogen atmosphere at 1373 K at 2000 psi at the temperature between 1973 and 2073 K in vacuum.)
2*	1011	Greenspan, J.	1953		293-978	BeO + Be + Si	Beryllium oxide + beryllium + silicone; hot-pressed -60 mesh high-fired beryllia, 15-25 μ beryllium, and ~43 μ 97% pure silicon at 2000 psi at the temperatures between 1973 K and 2073 K in vacuum.
3*	103	Curtis, C.E. and Johnson, J.R.	1957	L	298, 1273	Gd_2O_3 + Tb	Gadolinium oxide + terbium; 95+ Gd_2O_3, 2.0 Tb, other rare earth impurities < 0.5 each; slightly yellow powder consisting of particles 1 μ diameter; fired at 1773 K.
4*	1012	Harrington, L.C. and Rowe, G.H.	1963		293-1255	TiC + Co Kennametal, K 138 A	Titanium carbide + cobalt; 70 TiC, 20 Co, 10 Nb (TaTi)C; dimensions, 4 mm diameter, 50 mm long; Nb(TaTi)C added as a solid solution of NbC, TaC and TiC containing about 90% NbC; heating rate at about 1.67 C per minute gradually increased to 1.67 C per minute in vacuum; no permanent change in length; density 5.75 g cm^{-3}; reported error 3%.
5*	1013	Redmond, J.C. and Smith, E.N.	1949		310, 1255	TiC + Co	Titanium carbide + cobalt; 80 TiC, 20 Co; density 5.42 g cm^{-3}.
6*	1013	Redmond, J.C. and Smith, E.N.	1949		310, 1255	TiC + Co	Titanium carbide + cobalt; 66.3 TiC, 18.7 Co, 15 Nb(TaTi)C; density 5.78 g cm^{-3}.
7*	447	Sheolin, T.S., Newkirk, H.W., Stevens, E.G., and Greenhouse, H.M.	1956	L	303-1101	TiC + Steel Alloy T-420-G	Titanium carbide + steel alloy; 70 TiC and 30 Fernico; 325 mesh, free carbon 0.05 maximum, Norton Company, Worchester, Massachusetts; Fernico alloy composed of 54.0 Fe, 28.0 Ni, 18.0 C; sample prepared in 500 gram batches by milling in 1 qt. steel mills; batches then air dried, granulated through a 42 mesh screen; specimen formed by pressing between 2 punches as bar 0.5 x 0.15 x 4.5 in.; zero-point correction is 0.002%.
8*	447	Sheolin, T.S., et al.	1956	L	303-1079	TiC + Steel Alloy T-520-G	Titanium carbide + steel alloy; 70.0 TiC and 30.0 Fernico; similar to the above specimen; Fernichrome alloy composed of 37.0 Fe, 30.0 Ni, 25.0 Co, 8.0 Cr; zero-point correction is 0.006%.
9*	447	Sheolin, T.S., et al.	1956	L	1079-580	TiC + Steel Alloy T-520-G	Titanium carbide + steel alloy; the above specimen; expansion measured with decreasing temperature; zero-point correction is -0.043%.
10*	1016	Straumanis, M.E. and Ejima, T.	1957	X	283, 333	Ti_2O_3 + Ti Sample A	Dititanium trioxide + titanium; Ti_2O_3 with 0.8% b.w. free Ti; solid solution; prepared by heating in vacuum at 1673 K; cobalt radiation used to produce interferences 13.10 and 30.12 at angles 77.55 and 82.26° respectively; expansion measured along a-axis; lattice constant 5.1482 Å reported at 298 K.
11*	1016	Straumanis, M.E. and Ejima, T.	1957	X	283, 333	Ti_2O_3 + Ti Sample A	Dititanium trioxide + titanium; the above specimen; expansion measured along c-axis; lattice constant 13.6362 Å reported at 298 K.
12*	1016	Straumanis, M.E. and Ejima, T.	1957	X	283, 333	Ti_2O_3 + Ti Sample C	Dititanium trioxide + titanium; Ti_2O_3 with 3.67% b.w. free Ti; solid solution; prepared by heating in vacuum at 1673 K; free titanium in the interstitial space of Ti_2O_3; expansion measured along a-axis; lattice constant 5.1402 Å reported at 298 K.
13*	1016	Straumanis, M.E. and Ejima, T.	1957	X	283, 333	Ti_2O_3 + Ti Sample C	Dititanium trioxide + titanium; the above specimen; expansion measured along c-axis; lattice constant 13.6595 Å reported at 298 K.

* No figure given.

SPECIFICATION TABLE 362. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERMETS (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
14*	733	Meerson, G.A., Kotelnikov, R.B., and Bashlikov, S.N.	1960		293-873	UC + U	Uranium carbide + uranium; specimen pressed from mixture UC and 20% U, sintered in vacuum furnace.
15*	1018	Paprocki, S.J., Keller, D.L., Cunningham, G.W., and Kizer, D.E.	1960		293-1223	UO_2 + Cr TC-104	Uranium dioxide + chromium; UO_2 + 20 vol.% Cr; gas pressure bonded 80 vol.% -100 + 140 mesh spherical UO_2 particles and -325 mesh Cr at 1533 K and at 10,000 psi of helium gas pressure for 3 hr; maximum heating rate 3 C per minute; measured in a vacuum of approximately 5 x 10^{-5} mm Hg; first thermal cycle; 97.1 theoretical density; reported error < 2%.
16*	1018	Paprocki, S.J., et al.	1960		1223-293	UO_2 + Cr TC-104	Uranium dioxide + chromium; the above specimen; expansion measured with decreasing temperature.
17*	1018	Paprocki, S.J., et al.	1960		293-1223	UO_2 + Cr TC-104	Uranium dioxide + chromium; the above specimen; second thermal cycle of TC-104.
18*	1018	Paprocki, S.J., et al.	1960		1223-293	UO_2 + Cr TC-104	Uranium dioxide + chromium; the above specimen; expansion measured with decreasing temperature.
19*	213	McCreight, L.R.	1952	I	293-504	UO_2 + Zr	Uranium dioxide + zirconium; 43 UO_2 and 57 Zr; specimen pressed from ZrH_2 and UO_2, hydride decomposed; specimen sintered at 1573 K in vacuum to ~ 80% density.
20*	898	Loch, L.D., Engle, G.B., Snyder, M.J., and Duckworth, W.H.	1956		293-1223	USi_3 + W	Uranium trisilicide + tungsten; 96 USi_3 and 4 W; powder sintered at 1523 K in argon for 15 hr.
21*	1021	Goodman, E., Bargero, G.F., and Huminik, J.	1962	L	311-1089	ZrB_2 + Cr	Zirconium diboride + chromium; electroformed tube of cermet, 1/2 in. I.D. 0.0025 in. thick, 2 in. long; test in tube furnace, heating cycle.
22*	1021	Goodman, E., et al.	1962	L	1089-366	ZrB_2 + Cr	Zirconium diboride + chromium; the above specimen; expansion measured with decreasing temperature.

* No figure given.

DATA TABLE 362. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERMETS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, -]

T	$\Delta L/L_0$
CURVE 1*	
203	0.000
373	0.040
473	0.112
573	0.180
673	0.260
773	0.350
873	0.440
973	0.552
1073	0.680
CURVE 2*	
293	0.000
373	0.010
473	0.040
600	0.150
673	0.251
703	0.285
800	0.410
935	0.605
978	0.693
CURVE 3*	
298	0.005
1273	1.029
CURVE 4*	
293	0.000
366	0.053
477	0.131
588	0.220
699	0.312
810	0.414
922	0.518
1033	0.621
1144	0.732
1255	0.846
CURVE 5*	
310	0.016
1255	0.866

T	$\Delta L/L_0$
CURVE 6*	
310	0.014
1255	0.779
CURVE 7*	
303	0.002
321	0.007
354	0.024
377	0.038
408	0.055
446	0.081
471	0.096
495	0.109
530	0.138
573	0.166
616	0.201
646	0.230
686	0.266
720	0.295
754	0.332
780	0.375
803	0.388
840	0.423
859	0.456
890	0.490
945	0.544
1010	0.615
1101	0.680
CURVE 8*	
303	0.006
328	0.020
366	0.043
381	0.058
404	0.067
449	0.093
484	0.120
514	0.139
549	0.164
575	0.183
589	0.203
614	0.220
659	0.259
699	0.301

T	$\Delta L/L_0$
CURVE 8 (cont.)*	
733	0.331
771	0.362
803	0.392
838	0.415
869	0.443
886	0.465
904	0.484
930	0.508
954	0.530
974	0.549
996	0.577
1033	0.612
1071	0.650
1079	0.657
CURVE 9*	
1079	0.608
1033	0.573
1008	0.548
922	0.470
894	0.441
839	0.401
800	0.364
773	0.334
745	0.314
714	0.288
694	0.271
669	0.252
650	0.236
636	0.224
621	0.210
614	0.196
587	0.183
580	0.170
CURVE 10*	
283	-0.017
333	0.067
CURVE 11*	
283	-0.023
333	0.094

T	$\Delta L/L_0$
CURVE 12*	
283	0.091
333	-0.363
CURVE 13*	
283	-0.027
333	0.110
CURVE 14*	
293	0.000
373	0.086
473	0.206
573	0.337
673	0.483
773	0.638
873	0.808
CURVE 15*	
293	0.000
373	0.061
473	0.142
573	0.230
673	0.331
773	0.437
873	0.545
973	0.660
1073	0.772
1173	0.898
1223	0.958
CURVE 16*	
1223	0.949
1173	0.889
1073	0.772
973	0.660
873	0.545
773	0.442
673	0.331
573	0.244
473	0.153
373	0.067
293	0.000

T	$\Delta L/L_0$
CURVE 17*	
293	0.000
373	0.066
473	0.151
573	0.244
673	0.356
773	0.451
873	0.563
973	0.673
1073	0.788
1173	0.906
1223	0.967
CURVE 18*	
1223	0.958
1173	0.898
1073	0.780
972	0.666
873	0.557
773	0.451
673	0.346
573	0.249
473	0.158
373	0.070
293	0.000
CURVE 19*	
293	0.000
299	0.006
322	0.033
350	0.068
381	0.101
400	0.134
421	0.168
438	0.202
456	0.232
472	0.264
484	0.296
492	0.324
504	0.351
CURVE 20*	
293	0.000

T	$\Delta L/L_0$
CURVE 20 (cont.)*	
473	0.241
573	0.381
673	0.543
773	0.701
873	0.864
973	1.047
1073	1.225
1173	1.417
1223	1.516
CURVE 21*	
311	0.005
347	0.014
366	0.034
392	0.052
421	0.062
478	0.063
533	0.056
589	0.046
644	0.028
668	0.025
700	0.029
723	0.036
755	0.054
790	0.090
811	0.106
866	0.121
890	0.126
898	0.133
922	0.201
942	0.250
956	0.284
978	0.299
1033	0.332
1089	0.366
CURVE 22*	
1089	0.719
1058	0.660
1033	0.596
978	0.522
922	0.444
874	0.353

* No figure given.

DATA TABLE 362. THERMAL LINEAR EXPANSION OF MISCELLANEOUS CERMETS (continued)

T	$\Delta L/L_0$
CURVE 22 (cont.)*	
866	0.358
827	0.410
811	0.414
755	0.403
700	0.365
644	0.291
589	0.212
533	0.142
478	0.087
422	0.046
366	0.026

* No figure given.

8. GLASSES

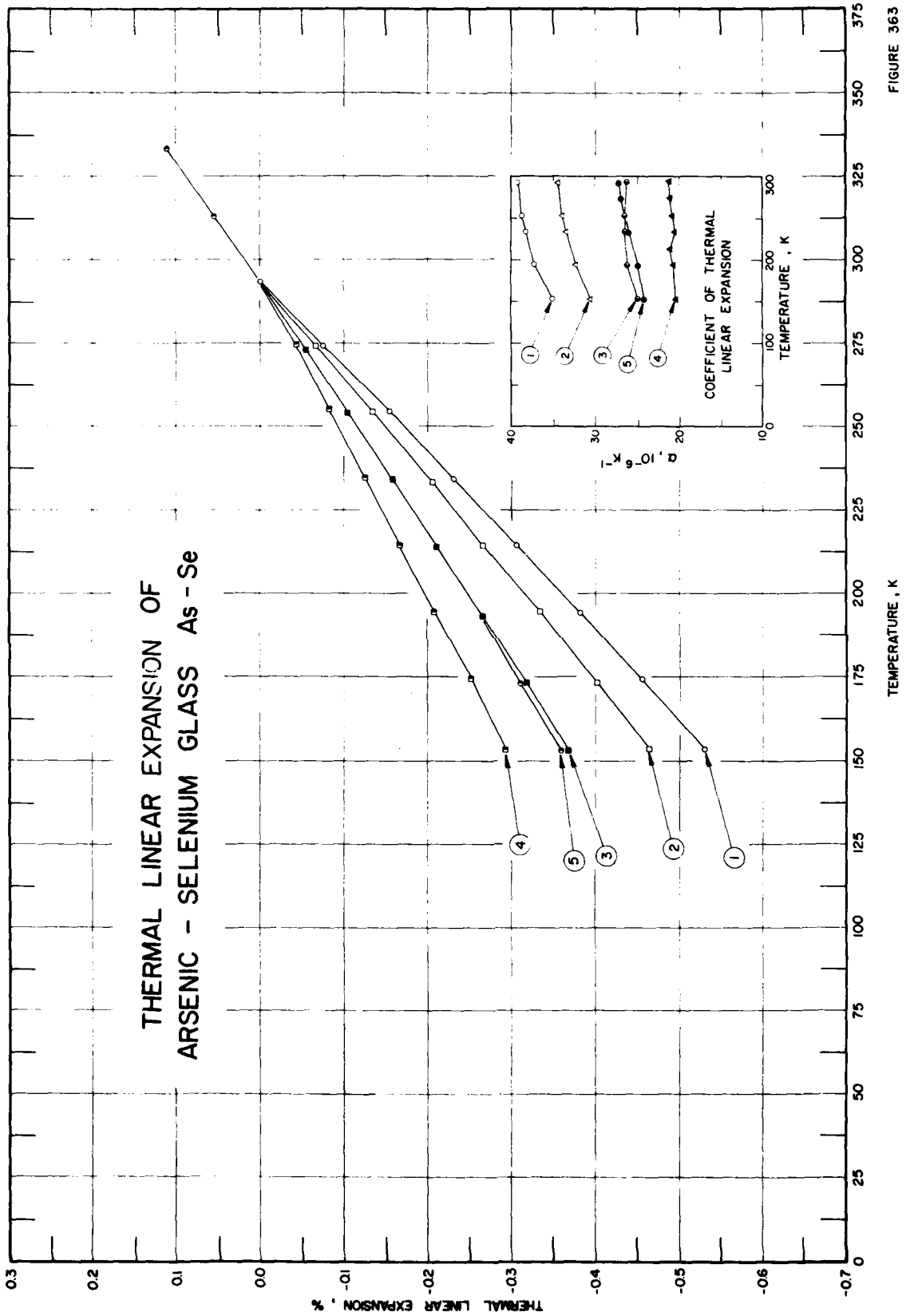

THERMAL LINEAR EXPANSION OF
ARSENIC - SELENIUM GLASS As - Se
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K
1
2
3
4
5

FIGURE 363

SPECIFICATION TABLE 363. THERMAL LINEAR EXPANSION OF ARSENIC-SELENIUM GLASS As-Se

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	536	Felty, E.J. and Myers, M.B.	1967	L	153-293		Specimen about 0.75 cm long; 9.54 As (10 at.%); bulk glasses prepared by direct reaction of elements in evacuated (10^{-5} torr) vitreous silica ampuls; calculated quantities of 99.9999 percent pure selenium and 99.997 percent pure β-arsenic, obtained from Atomergic Chemetals Co.; ampule heated to about 600 C, rocked for 24 hr, air-quenched to room temperature; heating rate 10 C/min.
2	536	Felty, E.J. and Myers, M.B.	1967	L	153-293		Similar to the above specimen except composition 19.17 As (20 at.%).
3	536	Felty, E.J. and Myers, M.B.	1967	L	153-293		Similar to the above specimen except composition 28.91 As (30 at.%).
4	536	Felty, E.J. and Myers, M.P.	1967	L	153-294		Similar to the above specimen except composition 38.74 As (40 at.%).
5	536	Felty, E.J. and Myers, M.P.	1967	L	153-333		Similar to the above specimen except composition 48.68 As (50 at.%).

DATA TABLE 363. THERMAL LINEAR EXPANSION OF ARSENIC-SELENIUM GLASS As-Se

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1‡		CURVE 2 (cont.)‡		CURVE 4‡		CURVE 5 (cont.)‡	
153	-0.530	254	-0.134	153	-0.294	234	-0.157*
174	-0.455	274	-0.066	174	-0.250	254	-0.105*
194	-0.381	293	0.000*	194	-0.209	273	-0.054*
214	-0.306	CURVE 3‡		214	-0.167	293	0.000*
234	-0.230	153	-0.369	234	-0.125	294	0.003*
254	-0.153	173	-0.318	255	-0.081	313	0.055
274	-0.075	193	-0.266	274	-0.041	333	0.110
293	0.000	214	-0.210	293	0.000*		
CURVE 2‡		234	-0.157	294	0.002*		
153	-0.463	254	-0.104	CURVE 5‡			
173	-0.401	273	-0.053	153	-0.360		
194	-0.333	293	0.000*	173	-0.311		
214	-0.268			193	-0.261*		
233	-0.205			214	-0.208*		

DATA TABLE 363. COEFFICIENT OF THERMAL LINEAR EXPANSION OF ARSENIC-SELENIUM GLASS As-Se

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α
CURVE 1‡		CURVE 2 (cont.)‡		CURVE 4‡		CURVE 5 (cont.)‡	
153	35.1	254	34.0	153	20.5	234	26.0
174	36.4	274	34.3	174	20.9	254	26.2
194	37.4	293	34.7	194	20.9	273	27.0
214	37.9	CURVE 3‡		214	21.1	293	27.4
234	38.4	153	25.0	234	20.8	294	27.2
254	38.9	173	25.9	255	21.0	313	27.6
274	39.1	193	26.3	274	21.3	333	27.9
293	39.4	214	26.6	293	21.4		
CURVE 2‡		234	26.7	294	21.2		
153	30.8	254	26.7	CURVE 5‡			
173	31.6	273	26.6	153	24.3		
194	32.5	293	26.3	173	24.7		
214	33.0			193	25.0		
233	33.5			214	25.3		

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

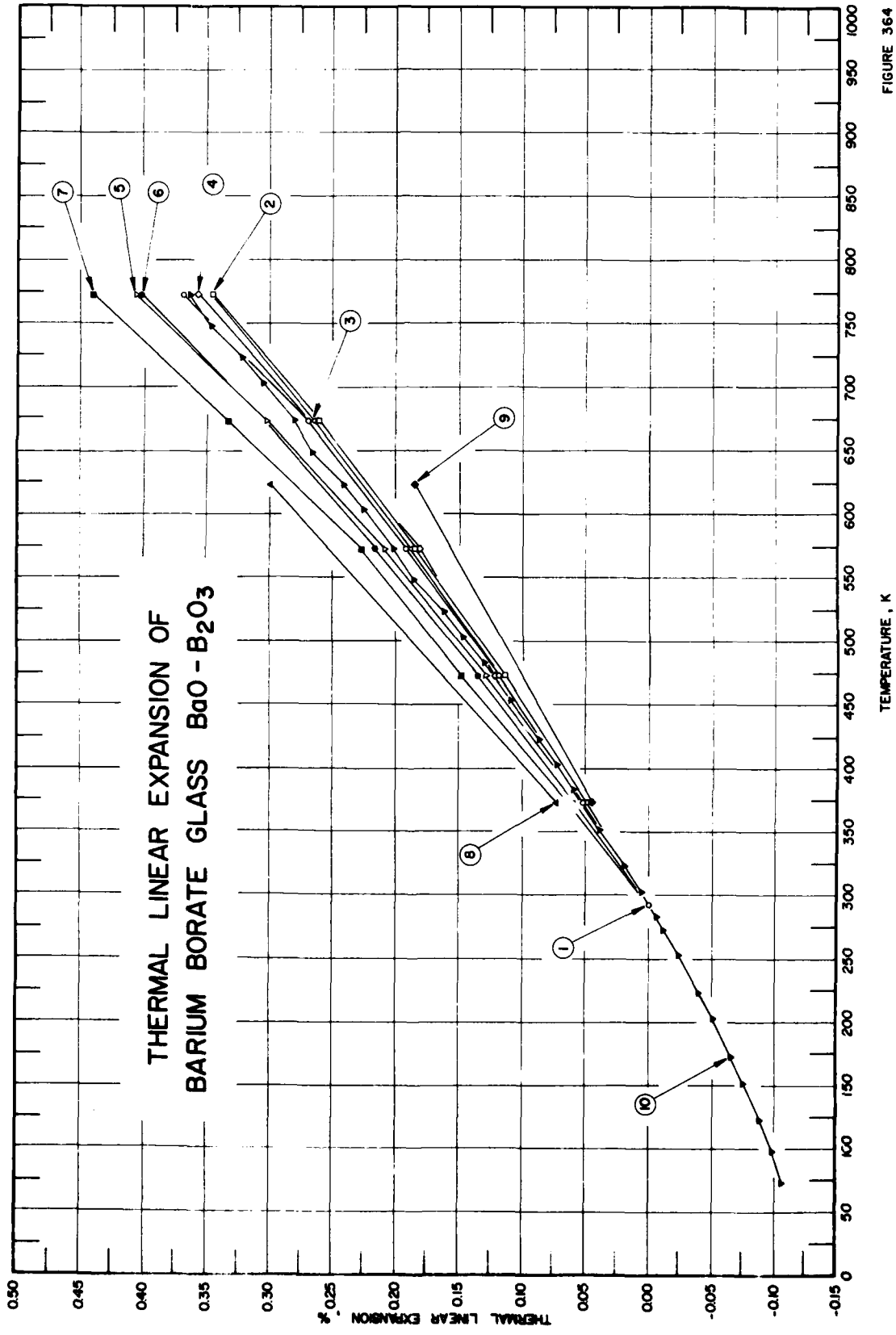

THERMAL LINEAR EXPANSION OF
BARIUM BORATE GLASS BaO - B2O3
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1
2
3
4
5
6
7
8
9
10

FIGURE 364

SPECIFICATION TABLE 364. THERMAL LINEAR EXPANSION OF BARIUM BORATE GLASS $BaO-B_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) B_2O_3	BaO	Composition (continued), Specifications, and Remarks
1	1082	Shermer, H. F.	1956	I	293-773		68.4	31.6	Sample cut from cylinder previously used for compressibility specimen; melting amounts of reagent-grade chemicals in platinum crucibles at approximately 1573 K; melts stirred until clear, poured onto cold iron mold; annealed by holding them at 863 K for 3 hr and cooling at 3 C/hr for 30 hr; glasses allowed to cool to room temperature in furnace; heating rate for measurements 2 C/min.
2	1082	Shermer, H. F.	1956	I	293-773		64.8	35.2	Similar to the above specimen; density 2.813 g/cm^3; deformation temperature 853 K.
3	1082	Shermer, H. F.	1956	I	293-773		59.4	40.6	Similar to the above specimen; density 2.996 g/cm^3; deformation temperature 868 K.
4	1082	Shermer, H. F.	1956	I	293-773		54.9	45.1	Similar to the above specimen; density 3.190 g/cm^3; deformation temperature 879 K.
5	1082	Shermer, H. F.	1956	I	293-773		52.5	47.5	Similar to the above specimen; density 3.289 g/cm^3; deformation temperature 879 K.
6	1082	Shermer, H. F.	1956	I	293-773		49.4	50.6	Similar to the above specimen; accuracy of coefficient $\pm 0.1 \times 10^{-6}$; density 3.429 g/cm^3; deformation temperature 883 K.
7	1082	Shermer, H. F.	1956	I	293-773		44.6	55.4	Similar to the above specimen; density 3.63 g/cm^3; deformation temperature 882 K.
8	1083	Hirayama, C.	1961	L	373,623		40.52	59.48	Annealed sample; sag point 559 C; specific gravity 3.74.
9	1083	Hirayama, C.	1961	L	373,623		64.49	35.51	Annealed sample; sag point 534 C; specific gravity 2.83.
10	1084	Waxler, R. M. and Cleek, G. W.	1973	I	73-773	E1583	59.0	41.0	Small tripod of same material and thickness which separated two optical flats; pattern of localized Fizeau-type interference fringes be seen through a Pulfrich viewer then illuminated with Collimated helium light of wavelength 587.6 nm; zero-point correction of -0.012%.

DATA TABLE 364. THERMAL LINEAR EXPANSION OF BARIUM BORATE GLASS $BaO \cdot B_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
373	0.053
473	0.120
573	0.192
673	0.270
773	0.368
CURVE 2	
293	0.000*
373	0.049
473	0.115
573	0.185
673	0.262
773	0.346
CURVE 3	
293	0.000*
373	0.051*
473	0.118*
573	0.188
673	0.265
773	0.347*
CURVE 4	
293	0.000*
373	0.053*
473	0.122
573	0.182
673	0.263*
773	0.357
CURVE 5	
293	0.000*
373	0.054*
473	0.129
573	0.208
673	0.303
773	0.406
CURVE 6	
293	0.000*
373	0.054*
CURVE 5 (cont.)	
473	0.129
573	0.208
673	0.303
773	0.406
CURVE 6	
293	0.000*
373	0.059
473	0.135
573	0.216
673	0.305*
773	0.401
CURVE 7	
293	0.000*
373	0.063
473	0.148
573	0.237
673	0.334
773	0.441
CURVE 8	
373	0.073
623	0.300
CURVE 9	
373	0.045
623	0.185
CURVE 10	
73	-0.106
83	-0.103*
93	-0.099
103	-0.096*
113	-0.092*
123	-0.088
133	-0.084*
143	-0.079*
153	-0.075
163	-0.070*
173	-0.066
183	-0.061*
193	-0.056*
203	-0.051
213	-0.046*
223	-0.040
233	-0.035*
243	-0.029*
253	-0.024
263	-0.018*
273	-0.012
283	-0.006
293	0.000*
303	0.006
313	0.012*
323	0.019
333	0.025*
343	0.032*
353	0.038
363	0.045*
373	0.052*
383	0.059
393	0.066*
403	0.073
413	0.080*
423	0.087
433	0.094*
443	0.102*
453	0.109
463	0.116*
473	0.124*
483	0.131
493	0.139*
503	0.147
513	0.154*
523	0.162
533	0.170*
543	0.178*
553	0.186
563	0.194*
573	0.201
583	0.209*
593	0.217*
603	0.225
613	0.233*
623	0.242
633	0.250*
643	0.258*
653	0.266
CURVE 10 (cont.)	
663	0.274*
673	0.282
683	0.290*
693	0.298*
703	0.306
713	0.315*
723	0.323
733	0.331*
743	0.339*
753	0.347
763	0.355*
773	0.363

* Not shown in figure.

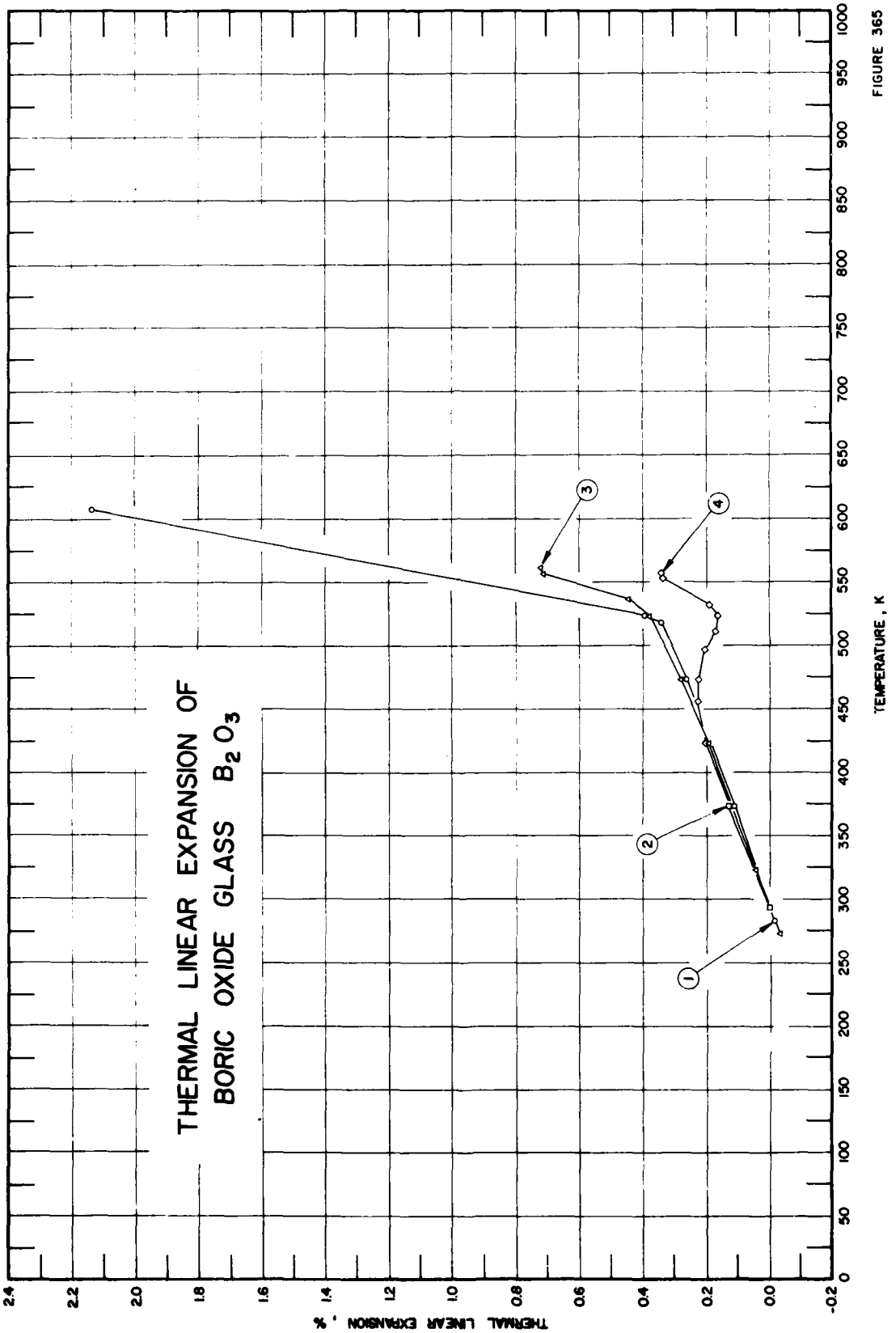

THERMAL LINEAR EXPANSION OF
BORIC OXIDE GLASS B_2O_3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1
2
3
4

FIGURE 365

SPECIFICATION TABLE 365. THERMAL LINEAR EXPANSION OF BORIC OXIDE GLASS B_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1085	Samsoen, M.	1925	L	283–607		Specimen of B_2O_3 put with mercury in thermometric reservoir; expansion calculated from heights of mercury column; thermal coefficient below 513 K less than 15×10^{-6}, above 523 K larger than 200×10^{-6}.
2	1082	Shermer, H. F.	1956	I	293–473		Fused B_2O_3; melting in platinum crucibles; glass stored in kerosine; sample cut and dried by heating to 473 K and allowed to cool in furnace overnight; heating rate for measurement 2 C/min, density 1.859 g/cm^3, deformation temperature 578 K.
3	1086	Gooding, E. J. and Turner, W. E. S.	1934		273–561		Annealed specimen; reported error < 1.5%.
4	1086	Gooding, E. J. and Turner, W. E. S.	1934		273–557		The above specimen; strained.

DATA TABLE 365. THERMAL LINEAR EXPANSION OF BORIC OXIDE GLASS B_2O_3

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
283	-0.014
373	0.116
473	0.265
518	0.342
523	0.398
607	2.141
CURVE 2	
293	0.000
373	0.129
473	0.267*
CURVE 3	
273	-0.030
323	0.046
373	0.124*
423	0.198
473	0.283
523	0.382
536	0.446
556	0.715
561	0.720
CURVE 4	
273	-0.030*
323	0.046*
373	0.124*
423	0.200
456	0.230
473	0.227
496	0.207
CURVE 4 (cont.)	
511	0.171
523	0.166
532	0.194
553	0.340
557	0.342

DATA TABLE 365. COEFFICIENT OF THERMAL LINEAR EXPANSION OF BORIC OXIDE GLASS B_2O_3

[Temperature, T, K; Coefficient of Expansion, $\Delta L/L_0$, %]

T	α
CURVE 1*,‡	
283	14.4
373	14.5
473	15.3
518	19
523	205
607	210

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

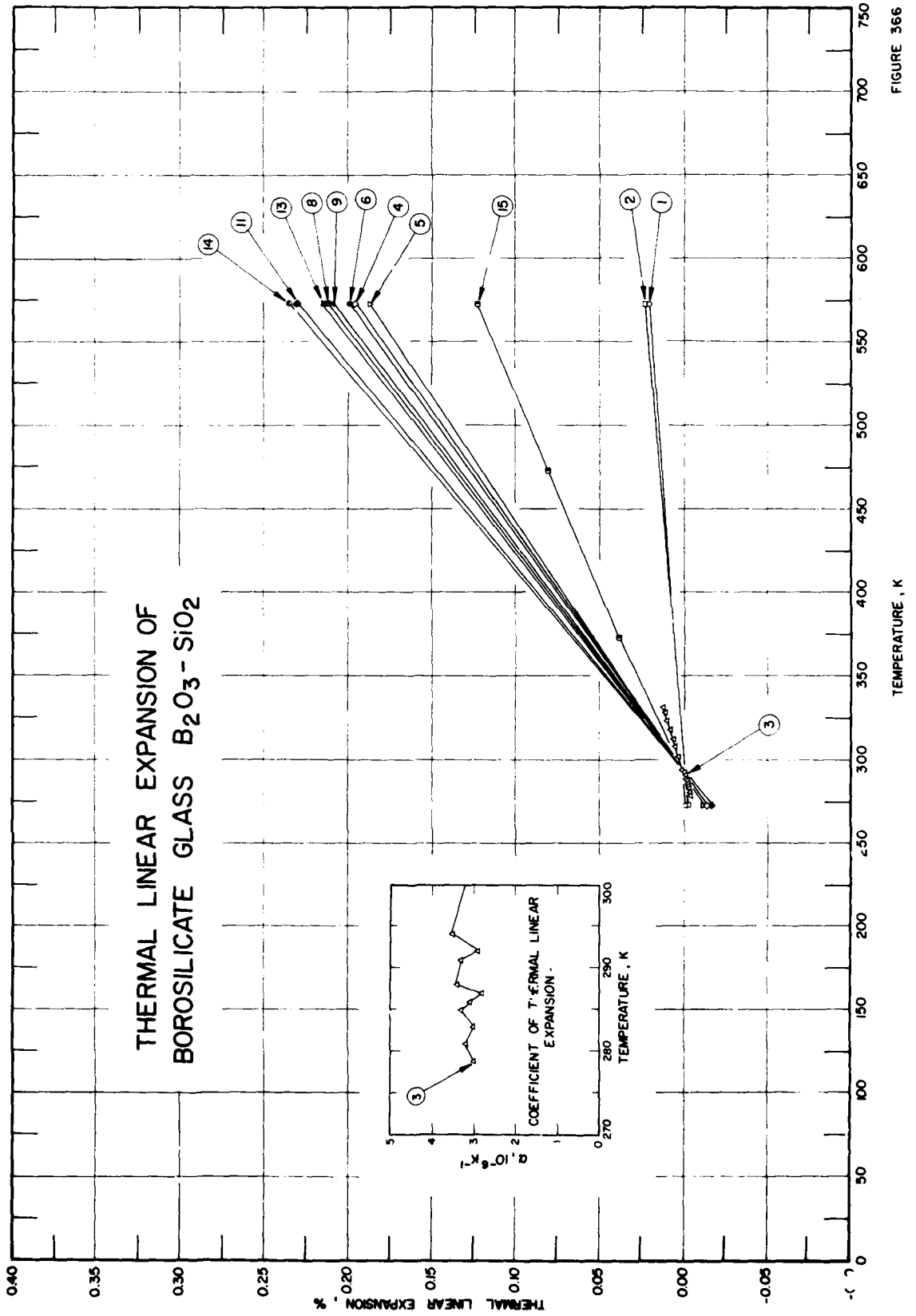

THERMAL LINEAR EXPANSION OF
BOROSILICATE GLASS B_2O_3 - SiO_2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION -
α , 10⁻⁶ K⁻¹
TEMPERATURE , K

FIGURE 366

SPECIFICATION TABLE 366. THERMAL LINEAR EXPANSION OF BOROSILICATE GLASS B_2O_3-SiO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1087	Nordberg, M. E.	1944	L	273, 573	Vycor-brand glass No. 790	96.0 SiO_2, 3.0 B_2O_3, 0.4 $R_2O_3 + RO_2$ (chiefly Al_2O_3), and traces of Na_2O, As_2O_3; produced without the use of excessive melting temperature; soft borosilicate glass melted, shaped; fluxes removed by leaching and the residual porous high-silica structure consolidated by heating; average expansion coefficient measured by dial method.
2	1087	Nordberg, M. E.	1944	L	273, 573	Vycor-brand glass No. 790	Similar to the above specimen; translucent white glass made by multiform process consisting of pulverizing the glass, forming it by method simulating ceramic techniques and refiring.
3	630, 631	Ballard, S. S., Browder, J. S., Kaylor, H. M., and Street, J. L.	1968	I	279-332	Borosilicate glass Pyrex 7740	Silicate glass containing at least 5.0 boric acid; cylindrical sample 10.0 mm diameter, 15.0 mm long, ends flat and parallel; obtained from Corning Glass Co.
4	1088	Simpson, H. E.	1961	S	273, 573	Borosilicate Glass No. 12	60.0 SiO_2, 30.0 Rb_2O, 10.0 B_2O_3; sample rod of glass 4 to 5 in. long; glass fused in porcelain crucibles, poured onto hot iron plate, cast into buttons 1.0 to 2.0 in. in diameter, 0.25 in. thick; slowly cooled in an oven from 1000 F; dial gauge used to measure expansion; density 3.16 g/cm^3.
5	1088	Simpson, H. E.	1961	S	273, 573	Borosilicate Glass No. 13	60.0 SiO_2, 20.0 Rb_2O, 20.0 B_2O_3; density 2.47 g/cm^3; similar to the above specimen.
6	1088	Simpson, H. E.	1961	S	273, 573	Borosilicate Glass No. 17	50.0 SiO_2, 40.0 Rb_2O, 10.0 B_2O_3; density 3.0 g/cm^3; similar to the above specimen.
7*	1088	Simpson, H. E.	1961	S	273, 573	Borosilicate Glass No. 18	50.0 SiO_2, 30.0 Rb_2O, 20.0 B_2O_3; density 2.71 g/cm^3; similar to the above specimen.
8	1088	Simpson, H. E.	1961	S	273, 573	Borosilicate Glass No. 24	40.0 SiO_2, 20.0 B_2O_3, 40.0 Rb_2O; density 3.02 g/cm^3; similar to the above specimen.
9	1088	Simpson, H. E.	1961	S	273, 573	Borosilicate Glass No. 25	40.0 SiO_2, 30.0 B_2O_3, 30.0 Rb_2O; density 2.41 g/cm^3; similar to the above specimen.
10*	1088	Simpson, H. E.	1961	S	273, 573	Borosilicate Glass No. 26	40.0 SiO_2, 40.0 B_2O_3, 20.0 Rb_2O; density 2.22 g/cm^3; similar to the above specimen.
11	1088	Simpson, H. E.	1961	S	273, 573	Borosilicate Glass No. 32	40.0 Rb_2O, 30.0 B_2O_3, 30.0 SiO_2; density 2.47 g/cm^3; similar to the above specimen.
12*	1088	Simpson, H. E.	1961	S	273, 573	Borosilicate Glass No. 33	40.0 B_2O_3, 30.0 SiO_2, 30.0 Rb_2O; density 2.57 g/cm^3; similar to the above specimen.
13	1088	Simpson, H. E.	1961	S	273, 573	Borosilicate Glass No. 34	50.0 B_2O_3, 30.0 SiO_2, 20.0 Rb_2O; density 2.12 g/cm^3; similar to the above specimen.
14	1088	Simpson, H. E.	1961	S	273, 573	Borosilicate Glass No. 40	50.0 Rb_2O, 30.0 B_2O_3, 20.0 SiO_2; density 2.46 g/cm^3; similar to the above specimen.
15	206	Souder, W., Hidnert, P., and Fox, J. F.	1934	N	293-573	1035A	150 mm in length with pointed ends; maximum diameter of specimen 12 mm.

* Not shown in figure.

DATA TABLE 366. THERMAL LINEAR EXPANSION OF BOROSILICATE GLASS B_2O_3-SiO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
273	-0.001
573	0.021
CURVE 2	
273	-0.002
573	0.023
CURVE 3‡	
279	-0.004
281	-0.004
283	-0.003
285	-0.003
286	-0.002
287	-0.002
289	-0.001
291	-0.001

T	$\Delta L/L_0$
CURVE 3 (cont.)‡	
293	0.000
295	0.001
302	0.003
308	0.005
313	0.006
318	0.008
323	0.010
329	0.011
331	0.012
CURVE 4	
273	-0.014
573	0.196
CURVE 5	
273	-0.013
573	0.187

T	$\Delta L/L_0$
CURVE 6	
273	-0.014*
573	0.199
CURVE 7*	
273	-0.014
573	0.199
CURVE 8	
273	-0.015*
573	0.212
CURVE 9	
273	-0.015*
573	0.209

T	$\Delta L/L_0$
CURVE 10*	
273	-0.015
573	0.208
CURVE 11	
273	-0.016
573	0.230
CURVE 12*	
273	-0.015
573	0.212
CURVE 13	
273	-0.015*
573	0.214

T	$\Delta L/L_0$
CURVE 14	
273	-0.017*
573	0.235
CURVE 15	
293	0.000*
373	0.038
473	0.081
573	0.123

DATA TABLE 366. COEFFICIENT OF THERMAL LINEAR EXPANSION OF BOROSILICATE GLASS B_2O_3-SiO_2

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3‡	
279	2.9
281	3.2
283	2.9
285	3.2
286	3.0
287	2.8
289	3.4
291	3.2
293	3.1
295	3.4
302	3.0*
308	3.0*
313	3.1*
318	3.0*
323	3.0*
329	3.0*
331	2.8*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

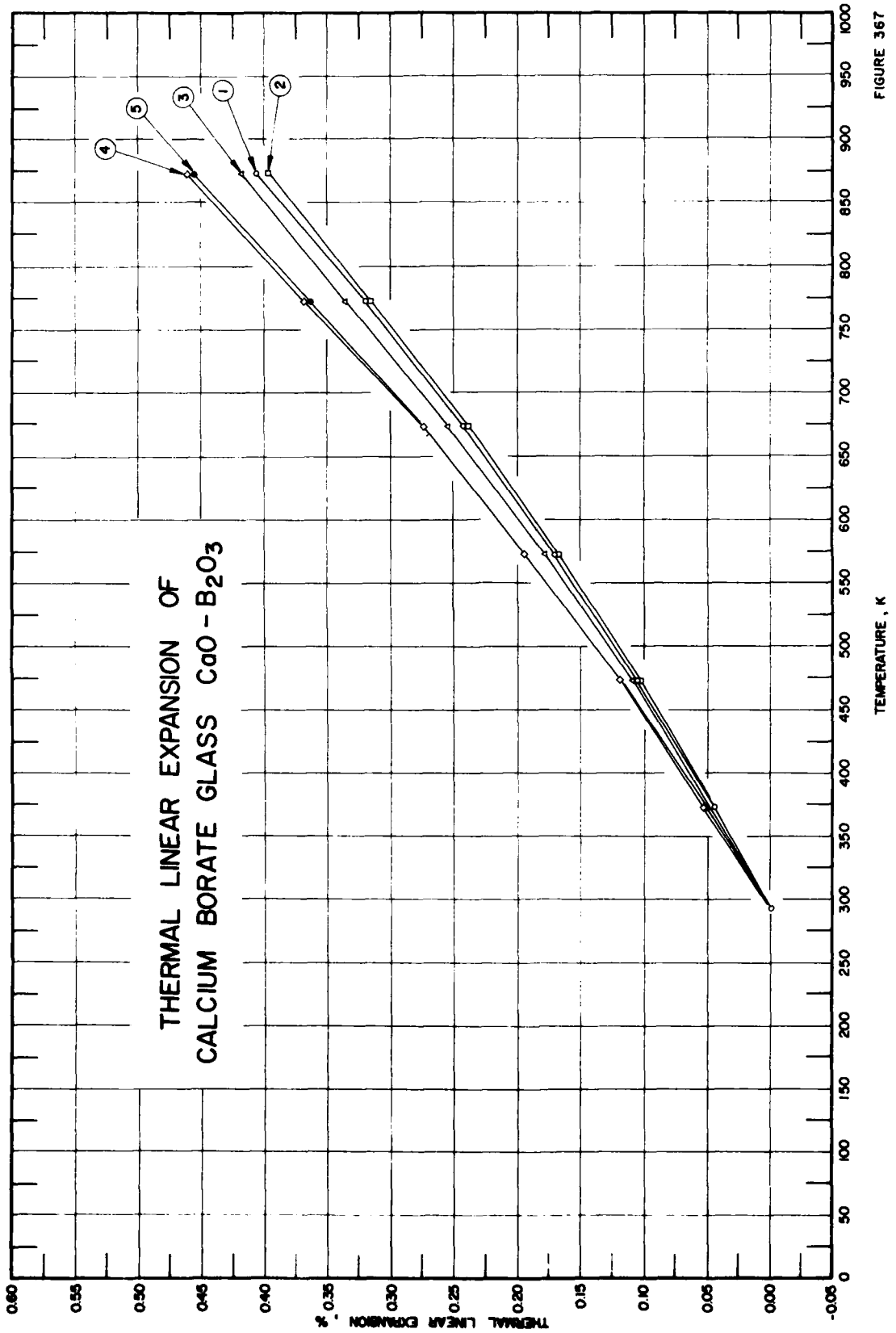

THERMAL LINEAR EXPANSION OF
CALCIUM BORATE GLASS CaO - B2O3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1
2
3
4
5

FIGURE 367

SPECIFICATION TABLE 367. THERMAL LINEAR EXPANSION OF CALCIUM BORATE GLASS $CaO-B_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) CaO	Composition (weight percent) B_2O_3	Composition (continued), Specifications, and Remarks
1	1082	Shermer, H. F.	1956	I	293-873	Calcium borate glasses	25.0	75.0	Sample cut from cylinder previously used for compressibility specimen; melting required amounts of reagent-grade chemicals in platinum crucibles at approximately 1573 K; melts stirred until clear, poured onto a cold iron mold; annealed by holding them at 863 K for 3 hr and cooling at 3 C/hr for 30 hr, glasses allowed to cool to room temperature in furnace; heating rate for measurement 2 C/min.
2	1082	Shermer, H. F.	1956	I	293-873	Calcium borate glasses	25.0	75.0	Similar to the above specimen; reannealed sample, by heating to 928 K for 3 hr cooled at approximately 3 C/hr until 728 K reached, allowed to cool in sealed furnace with no power.
3	1082	Shermer, H. F.	1956	I	293-873	Calcium borate glasses	27	73	Similar to the above specimen; heating rate 2.0 C/min.
4	1082	Shermer, H. F.	1956	I	293-873	Calcium borate glasses	30.2	69.8	Similar to the above specimen; deformation point 941 K (where viscous flow counteracts thermal expansion).
5	1082	Shermer, H. F.	1956	I	293-873	Calcium borate glasses	32.3	67.7	Similar to the above specimen; deformation point 942 K.

DATA TABLE 367. THERMAL LINEAR EXPANSION OF CALCIUM BORATE GLASS $CaO-B_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 3		CURVE 5	
293	0.000	293	0.000*	293	0.000*
373	0.045	373	0.046*	373	0.050
473	0.106	473	0.110	473	0.119*
573	0.171	573	0.178	573	0.195*
673	0.243	673	0.255	673	0.276*
773	0.320	773	0.336	773	0.364
873	0.407	873	0.419	873	0.457
CURVE 2		CURVE 4			
293	0.000*	293	0.000*		
373	0.044*	373	0.053		
473	0.104	473	0.120		
573	0.168	573	0.195		
673	0.239	673	0.274		
773	0.316	773	0.369		
873	0.397	873	0.461		

* Not shown in figure.

SPECIFICATION TABLE 368. THERMAL LINEAR EXPANSION OF CORNING 0080 GLASS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	1089	Dalton, R. H.	1956		829-273		Expansion measured with decreasing temperature; zero-point correction is -0.018%.
2*	1090	Partain, G. K., Piscopo, F. A., and Wilson, R. E.	1960		294-783	Soda Lime C. G. W. code 0080	Density 154.2 lbs/ft^3, strain point 959 F, annealing point 823 K, softening point 1008 K.

DATA TABLE 368. THERMAL LINEAR EXPANSION OF CORNING 0080 GLASS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*	
829	0.723	294	0.001
821	0.664	366	0.067
811	0.620	422	0.119
798	0.581	477	0.172
788	0.555	533	0.224
773	0.524	588	0.277
726	0.443	644	0.332
672	0.374	699	0.390
627	0.322	755	0.455
573	0.262	783	0.488
472	0.163		
372	0.070		
347	0.049		
273	-0.018		

* No figure given.

SPECIFICATION TABLE 369. THERMAL LINEAR EXPANSION OF CORNING 1173 GLASS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	149	Browder, J.S. and Ballard, S.S.	1969	L/E	65-310	Glass 1173	Specimen supplied by Texas Instruments Inc. of Dallas, Texas.

DATA TABLE 369. THERMAL LINEAR EXPANSION OF CORNING 1173 GLASS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡	
65	-0.303	140	-0.212	220	-0.103	300	0.010
70	-0.298	150	-0.199	230	-0.090	310	0.025
80	-0.286	160	-0.186	240	-0.075		
90	-0.275	170	-0.172	250	-0.061		
100	-0.263	180	-0.159	260	-0.047		
110	-0.250	190	-0.145	270	-0.033		
120	-0.238	200	-0.131	280	-0.019		
130	-0.225	210	-0.117	290	-0.004		

DATA TABLE 369. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CORNING 1173 GLASS

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡	
65	10.5	140	13.1	220	13.9	300	14.4
70	10.9	150	13.3	230	14.0	310	14.5
80	11.4	160	13.4	240	14.1		
90	11.8	170	13.5	250	14.1		
100	12.2	180	13.6	260	14.2		
110	12.5	190	13.7	270	14.3		
120	12.7	200	13.8	280	14.3		
130	12.9	210	13.8	290	14.4		

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 370. THERMAL LINEAR EXPANSION OF CORNING 7570 GLASS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	1069	Dalton, R. H.	1956		647-273		Expansion measured with decreasing temperature; zero-point correction is -0.015%.

DATA TABLE 370. THERMAL LINEAR EXPANSION OF CORNING 7570 GLASS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
647	0.408
643	0.371
632	0.331
614	0.296
595	0.267
573	0.240
474	0.146
373	0.060
273	-0.015

* No figure given.

SPECIFICATION TABLE 371. THERMAL LINEAR EXPANSION OF CORNING 9606 GLASS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	1052	Corning Glass Works	1958		73-1266	Pyroceram 9606	Hard, fine-grained crystalline material formed from special glasses; density 2.6 g cm^{-3}.

DAT \ TABLE 371. THERMAL LINEAR EXPANSION OF CORNING 9606 GLASS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡	
73	0.003	308	0.004	623	0.178	1023	0.338
123	0.007	323	0.012	673	0.195	1073	0.361
173	0.000	373	0.052	723	0.214	1123	0.382
203	0.003	423	0.091	773	0.233	1173	0.401
223	0.001	448	0.111	823	0.252	1223	0.423
245	-0.004	473	0.121	873	0.274	1266	0.440
273	-0.004	523	0.144	923	0.294		
293	0.000	573	0.162	973	0.317		

DATA TABLE 371. COEFFICIENT OF THERMAL LINEAR EXPANSION OF CORNING 9606 GLASS

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡	
293	1.9	650	3.9	1200	4.7
300	2.5	700	3.9	1300	4.8
325	5.2	750	4.0		
350	6.9	800	4.1		
400	7.6	850	4.2		
450	5.4	900	4.2		
500	3.6	950	4.3		
550	3.7	1000	4.4		
600	3.8	1100	4.6		

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

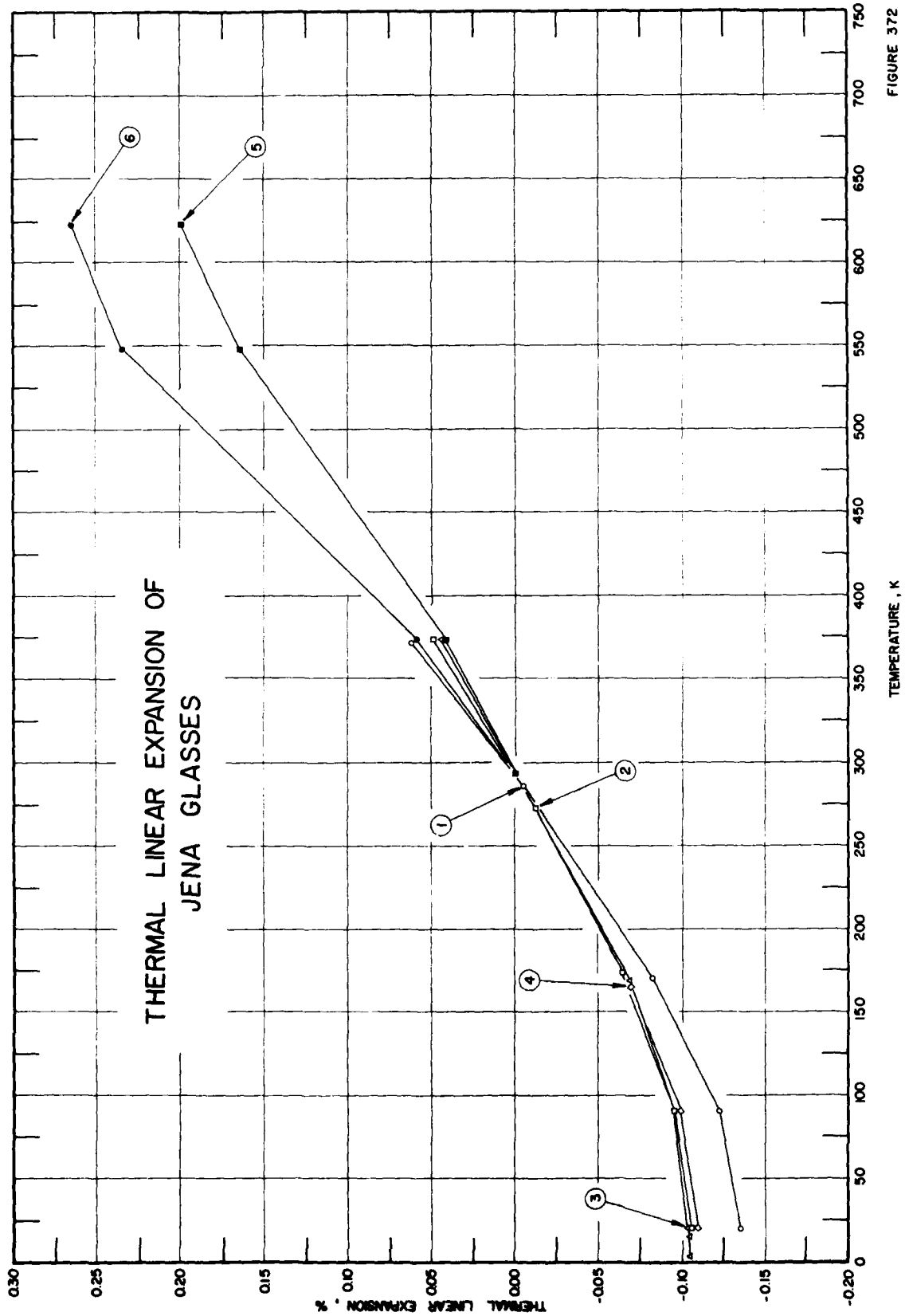

THERMAL LINEAR EXPANSION OF
JENA GLASSES
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
1
2
3
4
5
6

FIGURE 372

SPECIFICATION TABLE 372. THERMAL LINEAR EXPANSION OF JENA GLASS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1091	von Agt, F. P. G. A. J. and Ohmes, H. K.	1925		20-371		Expansion measured using micrometer.
2	1092	Keesom, W. H. and Dobersy'naki, D. W.	1934		20-373	2954[III]	Specimen annealed at 773 K; 93.851 cm long rod.
3	1093	Keesom, W. H. and Dobersy'naki, D. W.	1934	I	4-373	2954[III]	Ring of thoroughly annealed glass; wall thickness 1 mm, diameter of ring 30 mm, height ca. 6 mm; height of the ring in center at 0 C, 5.6586 mm; absolute measurements.
4	1093	[illegible]esom, W. H. and [illegible]obersy'naki, D. W.	1934	I	20-373	2954[III]	Similar to the above specimen except by comparator measurement method.
5	206	[illegible]ouder, W., Hidnert, P., and Fox, J. F.	1934	N	293-623	59[III]	Similar to borosilicate thermometer glass (1338B), not annealed; 150 mm long with pointed ends, maximum diameter 12 mm.
6	206	[illegible]ouder, W., et al.	1934	N	293-623	16[III]	150 mm long with pointed ends, maximum diameter 12 mm; developed for use with equivalent of Corning thermometer glass, 1336B, not annealed.

DATA TABLE 372. THERMAL LINEAR EXPANSION OF JENA GLASS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
20.4	-0.134
90.7	-0.123
170.4	-0.082
286.3	-0.005
371.0	0.062

CURVE 2

T	$\Delta L/L_0$
20	-0.105
90	-0.095
173	-0.064
273	-0.012
373	0.049

CURVE 3

T	$\Delta L/L_0$
4	-0.1043
15	-0.10399
20	-0.10390
90	-0.0958*
169.6	-0.0682
373	0.0422

CURVE 4

T	$\Delta L/L_0$
20	-0.1091
90	-0.0993
170	-0.0699
373	0.0454*

CURVE 5

T	$\Delta L/L_0$
293	0.000
373	0.042
573	0.165
623	0.198

CURVE 6

T	$\Delta L/L_0$
293	0.000*
373	0.059
573	0.235
623	0.264

* Not shown in figure.

SPECIFICATION TABLE 373. THERMAL LINEAR EXPANSION OF LIME GLASS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 20	50.0 CaO, 40.0 SiO_2, 10.0 Rb_2O; glass fused in porcelain crucibles, poured onto hot iron plate, cast into buttons 1.0 to 2.0 in. in diameter, 0.25 in. thick; slowly cooled in an oven from 1000 F; sample rod of glass 4 to 5 in. long; measured by a dial gauge; density 2.86 g cm^{-3}.
2*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass Specimen No. 25	40.0 CaO, 30.0 SiO_2, 30.0 Rb_2O; similar to the above specimen; density 2.88 g cm^{-3}.
3*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass Specimen No. 26	40.0 CaO, 40.0 SiO_2, 20.0 Rb_2O; similar to the above specimen; density 2.97 g cm^{-3}.
4*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 27	50.0 SiO_2, 40.0 CaO, 10 Rb_2O; similar to the above specimen; density 3.02 g cm^{-3}.
5*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 32	40.0 Rb_2O, 30.0 CaO, 30.0 SiO_2; similar to the above specimen; density 2.97 g cm^{-3}.
6*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 33	40.0 SiO_2, 30.0 CaO, 30.0 Rb_2O; similar to the above specimen; density 2.91 g cm^{-3}.
7*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 34	50.0 SiO_2, 30.0 CaO, 20.0 Rb_2O; similar to the above specimen; density 2.84 g cm^{-3}.
8*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 35	60.0 SiO_2, 30.0 CaO, 10.0 Rb_2O; similar to the above specimen; density 2.73 g cm^{-3}.
9*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 40	50.0 Rb_2O, 30.0 SiO_2, 20.0 CaO; similar to the above specimen; density 2.94 g cm^{-3}.
10*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 41	40.0 SiO_2, 40.0 Rb_2O, 20.0 CaO; similar to the above specimen; density 2.95 g cm^{-3}.
11*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 42	50.0 SiO_2, 30.0 Rb_2O, 20.0 CaO; similar to the above specimen; density 2.90 g cm^{-3}.
12*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 43	60.0 SiO_2, 20.0 CaO, 20.0 Rb_2O; similar to the above specimen; density 2.72 g cm^{-3}.
13*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 44	70.0 SiO_2, 20.0 CaO, 10.0 Rb_2O; similar to the above specimen; density 2.60 g cm^{-3}.
14*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 49	60.0 Rb_2O, 30.0 SiO_2, 10.0 CaO; similar to the above specimen; density 2.86 g cm^{-3}.
15*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 50	50.0 Rb_2O, 40.0 SiO_2, 10.0 CaO; similar to the above specimen; density 2.92 g cm^{-3}.
16*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 51	50.0 SiO_2, 40.0 Rb_2O, 10.0 CaO; similar to the above specimen; density 2.92 g cm^{-3}.
17*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 52	60.0 SiO_2, 30.0 Rb_2O, 10.0 CaO; similar to the above specimen; density 2.72 g cm^{-3}.
18*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 53	70.0 SiO_2, 20.0 Rb_2O, 10.0 CaO; similar to the above specimen; density 2.58 g cm^{-3}.
19*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 61	50.0 SiO_2, 50.0 Rb_2O; similar to the above specimen; density 2.90 g cm^{-3}.

* No figure given.

SPECIFICATION TABLE 373. THERMAL LINEAR EXPANSION OF LIME GLASS (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
20*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 62	60.0 SiO_2, 40.0 Rb_2O; similar to the above specimen; density 2.74 g cm^{-3}.
21*	1088	Simpson, H. E.	1961	S	273, 573	Lime glass No. 63	70.0 SiO_2, 30.0 Rb_2O; similar to the above specimen; density 2.56 g cm^{-3}.

* No figure given.

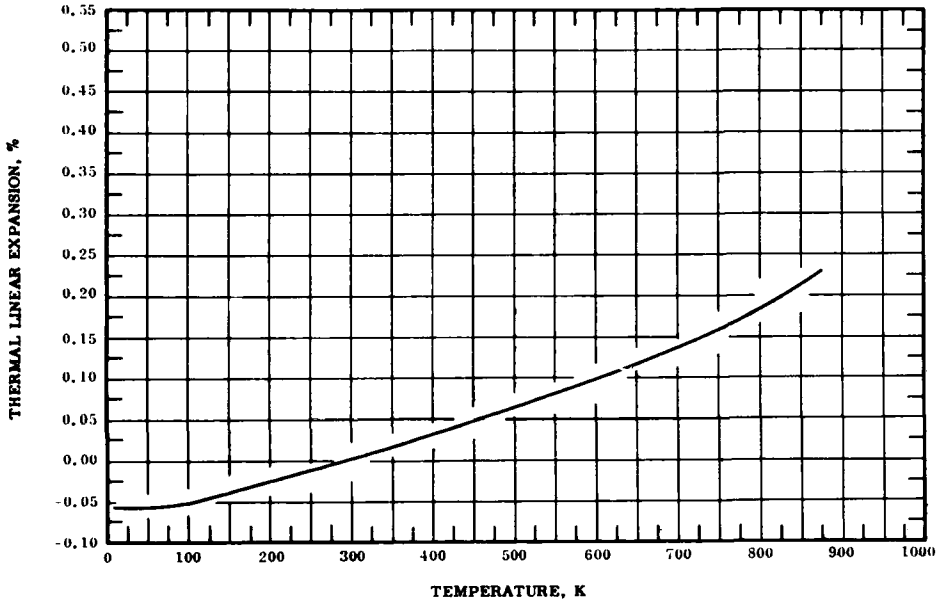
DATA TABLE 373. THERMAL LINEAR EXPANSION OF LIME GLASS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 11*		CURVE 21*	
273	-0.032	273	-0.032	273	-0.024
573	0.456	573	0.456	573	0.336
CURVE 2*		CURVE 12*			
273	-0.041	273	-0.025		
573	0.576	573	0.350		
CURVE 3*		CURVE 13*			
273	-0.034	273	-0.017		
573	0.476	573	0.245		
CURVE 4*		CURVE 14*			
273	-0.026	273	-0.048		
573	0.364	573	0.677		
CURVE 5*		CURVE 15*			
273	-0.044	273	-0.040		
573	0.621	573	0.571		
CURVE 6*		CURVE 16*			
273	-0.037	273	-0.036		
573	0.518	573	0.504		
CURVE 7*		CURVE 17*			
273	-0.029	273	-0.028		
573	0.406	573	0.394		
CURVE 8*		CURVE 18*			
273	-0.021	273	-0.020		
573	0.305	573	0.291		
CURVE 9*		CURVE 19*			
273	-0.044	273	-0.036		
573	0.627	573	0.509		
CURVE 10*		CURVE 20*			
273	-0.042	273	-0.031		
573	0.599	573	0.439		

* No figure given.

FIGURE AND TABLE NO. 374R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF PYREX GLASS



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
5	-0.054	-0.5
10	-0.054	-0.4
20	-0.054	-0.1
30	-0.054	0.2
40	-0.054	0.4
50	-0.054	0.6
60	-0.053	0.7
70	-0.052	0.8
80	-0.051	0.9
90	-0.050	1.0
100	-0.049	1.5
150	-0.039	2.5
200	-0.025	2.7
250	-0.011	2.8
293	0.000	2.8
350	0.017	2.9
400	0.032	3.0
450	0.048	3.1
500	0.065	3.3
550	0.080	3.5
600	0.099	3.7
650	0.117	4.0
700	0.143	4.3
750	0.155	4.6
800	0.180	5.0
850	0.210	5.4
875	0.230	5.7

REMARKS

The recommended values are considered accurate to within ±5% and are represented approximately by the following equations:

$$\Delta L/L_0 = -0.053 - 7.085 \times 10^{-5} T + 1.686 \times 10^{-6} T^2 - 5.560 \times 10^{-9} T^3 \quad (5\text{-}100\ K)$$

$$\Delta L/L_0 = -0.083 + 3.172 \times 10^{-4} T - 1.664 \times 10^{-7} T^2 + 2.347 \times 10^{-10} T^3 \quad (100\text{-}875\ K)$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equations and are considered accurate to about ±7%.

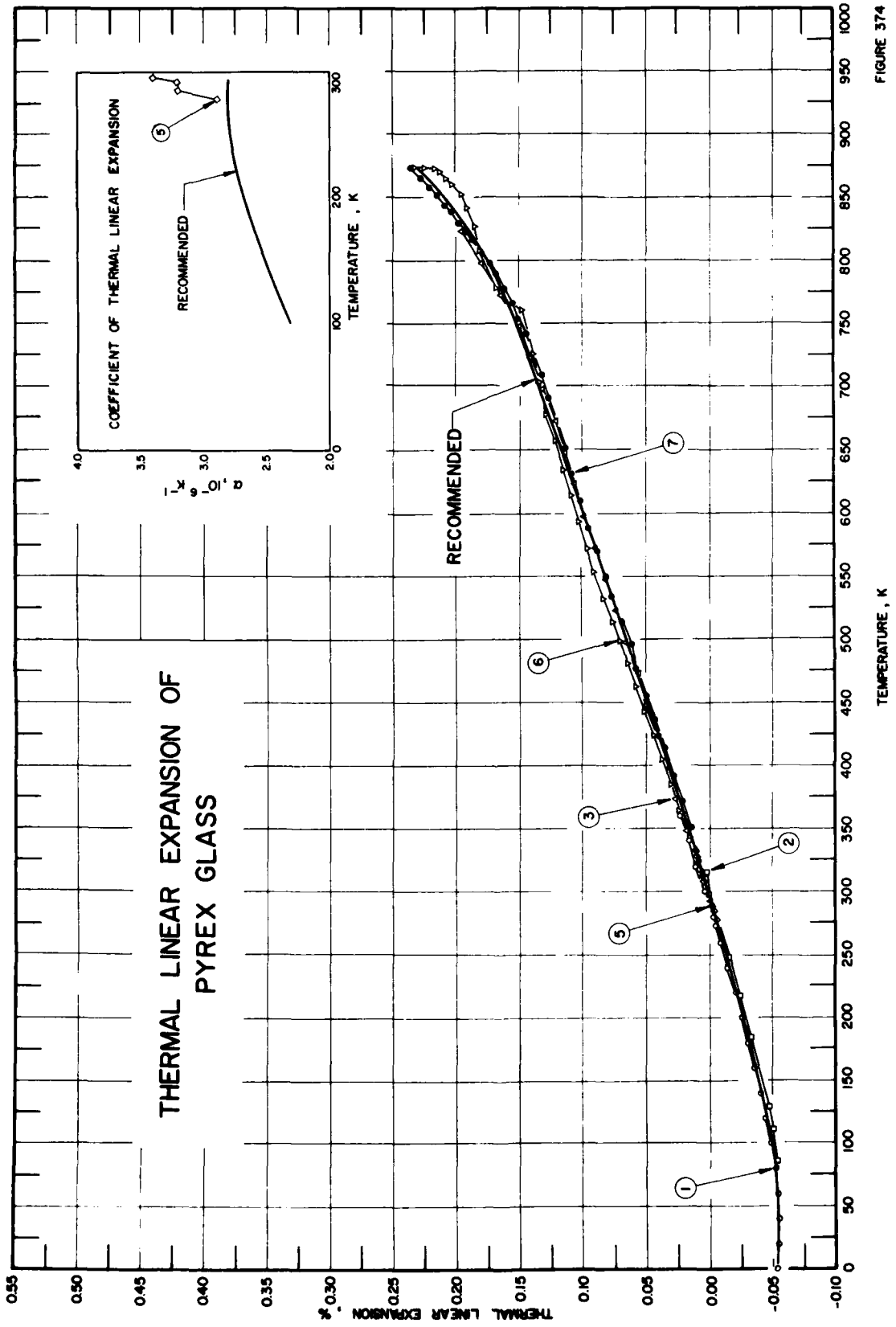

THERMAL LINEAR EXPANSION OF PYREX GLASS
RECOMMENDED
COEFFICIENT OF THERMAL LINEAR EXPANSION
RECOMMENDED
α ,10⁻⁶ K⁻¹
TEMPERATURE , K
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K

FIGURE 374

SPECIFICATION TABLE 374. THERMAL LINEAR EXPANSION OF PYREX GLASS

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	798	Laquer, H. L.	1952	L	0-360		Pyrex rod, 5 mm diameter x 25.4 mm long; zero-point correction is -0.004%; reported error 1.0%.
2	169	Buffington, R. M. and Latimer, W. M.	1926	I	87-316	Pyrex G702-EJ	Pyrex glass G702-EJ; specimen ring cut from 2.3 cm tubing, finished to give 3 point support at each end.
3	207	Burger, E. E.	1934	L	293-823		Specimen tested in form of rod 0.25 in. diameter, 12 in. long; measured with modified method.
4*	571	Kasai, N.	1968	E'	0-60		Rod form sample, about 2 cm long, 8 mm diameter; this curve is here reported using the first given temperature (0 K) as reference temperature at which $\Delta L/L_0 = 0$.
5	630, 631	Ballard, S. S., Browder, J. S., Kaylor, H. M., and Streete, J. L.	1967	I	279-332	Pyrex 7740	Specimen containing at least 5.0 boric acid; cylindrical sample 10.0 mm diameter, 15.0 mm long, ends flat and parallel; obtained from Corning Glass Co.
6	1094	Tool, A. Q. and Saunders, J. B.	1948		293-873	Ordinary Pyrex	Specimen of pyrex tubing; zero-point correction is -0.026%.
7	1094	Tool, A. Q. and Saunders, J. B.	1948		873-293	Ordinary Pyrex	The above specimen; expansion measured with decreasing temperature; zero-point correction is -0.005%.

* Not shown in figure.

DATA TABLE 374. THERMAL LINEAR EXPANSION OF PYREX GLASS

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
0	-0.053
20	-0.054
40	-0.055
60	-0.054
80	-0.052
100	-0.048
120	-0.044
140	-0.040
160	-0.035
180	-0.030
200	-0.025
220	-0.020
240	-0.014
260	-0.008
273.2	-0.004
280	-0.002
300	0.004
320	0.011
340	0.017
360	0.024

CURVE 2

T	$\Delta L/L_0$
86.7	-0.0535
111.8	-0.0507
130.4	-0.0476
185.1	-0.0328
218.3	-0.0248
248.9	-0.0151
298.0	0.0018
315.9	0.0024

CURVE 3

T	$\Delta L/L_0$
293	0.000
323	0.009
348	0.018
373	0.027
398	0.032
423	0.041
448	0.050
473	0.057
498	0.066
523	0.074
548	0.082
573	0.090

CURVE 3 (cont.)

T	$\Delta L/L_0$
598	0.098
623	0.106
648	0.114
673	0.122
698	0.132
723	0.142
748	0.150
773	0.165
798	0.180
823	0.197

CURVE 4*, †

T	$\Delta L/L_0$
0	0.000
20	-0.001
40	-0.002
60	-0.0015

CURVE 5‡

T	$\Delta L/L_0$
279	-0.004
281	-0.004*
283	-0.003*
285	-0.003
286	-0.002*
287	-0.002*
289	-0.001
291	-0.001*
293	0.000*
295	0.001*
302	0.003*
308	0.005
313	0.006
318	0.008
323	0.009*
329	0.011
332	0.012

CURVE 6

T	$\Delta L/L_0$
293	0.000*
321	0.010*
343	0.017
365	0.025
385	0.031
405	0.038

CURVE 6 (cont.)

T	$\Delta L/L_0$
424	0.045
443	0.052
462	0.059
481	0.065
499	0.071
514	0.077
533	0.084
553	0.091
572	0.097
594	0.103
613	0.109
634	0.116
657	0.122
678	0.129
703	0.134
726	0.140
761	0.149
778	0.169
808	0.157
827	0.161
841	0.167
852	0.172
860	0.179
865	0.184
870	0.189
873	0.193
873	0.200
873	0.208

CURVE 7

T	$\Delta L/L_0$
873	0.236
865	0.229
858	0.222
851	0.216
844	0.210
838	0.204
830	0.199
823	0.193
816	0.187
807	0.181*
798	0.174
790	0.169
779	0.163
767	0.156
755	0.151

CURVE 7 (cont.)

T	$\Delta L/L_0$
742	0.145
727	0.139*
710	0.133
691	0.127
673	0.121*
652	0.114
631	0.108
610	0.102
589	0.096
570	0.089
550	0.082
535	0.077
515	0.070
496	0.063
477	0.058
456	0.050
436	0.044
415	0.036
392	0.029
371	0.022
351	0.015
329	0.009*
293	0.000*

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 374. COEFFICIENT OF THERMAL LINEAR EXPANSION OF PYREX GLASS

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 5‡	
279	2.9
281	3.2
283	2.9
285	3.2
286	3.0
287	2.8
289	3.4
291	3.2
293	3.1
295	3.4
302	3.0*
308	3.0*
313	3.1*
318	3.0*
323	3.0*
329	3.0*
332	2.8*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

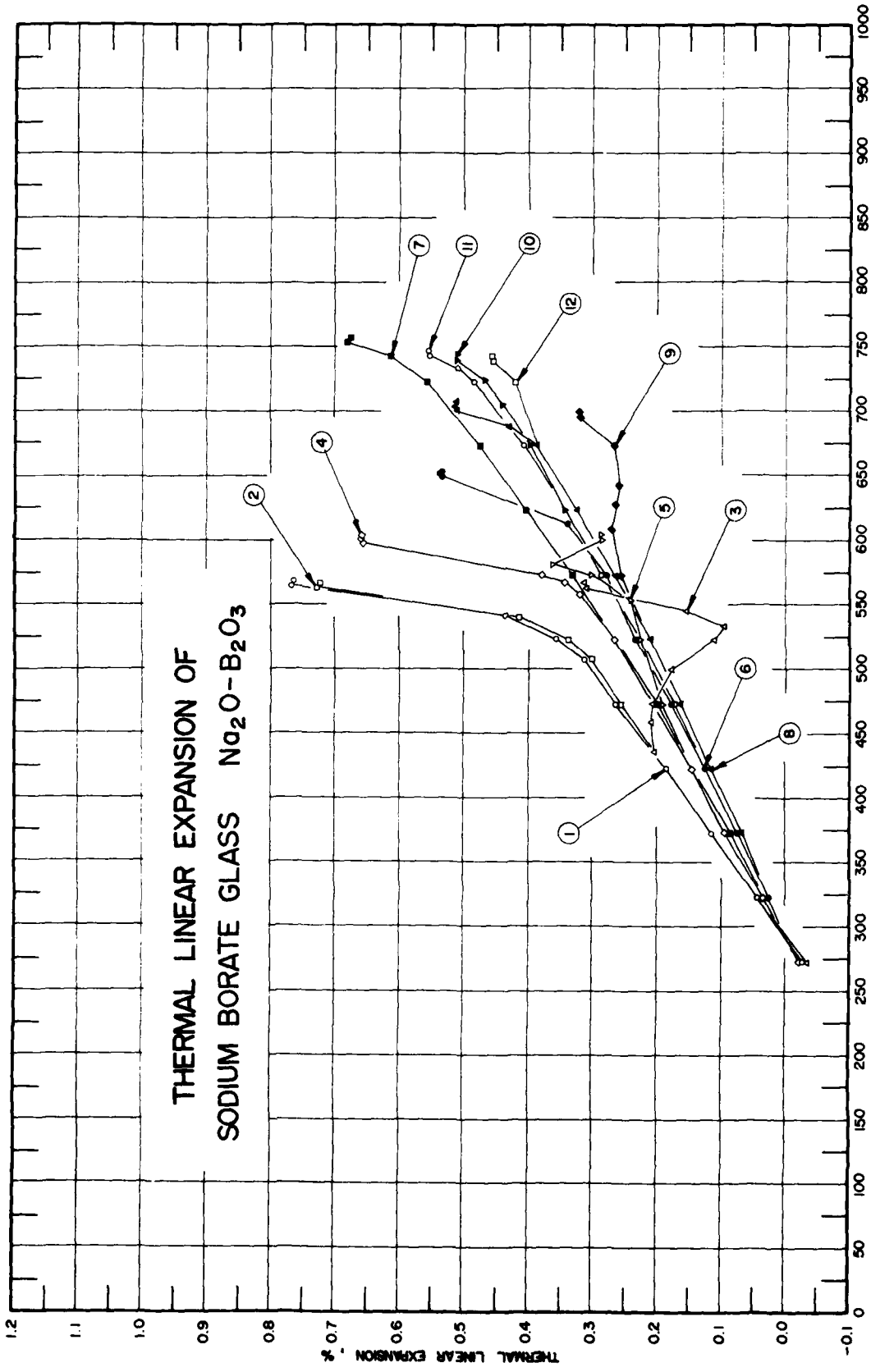

THERMAL LINEAR EXPANSION OF
SODIUM BORATE GLASS $Na_2O-B_2O_3$
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1
2
3
4
5
6
7
8
9
10
11
12

FIGURE 375

SPECIFICATION TABLE 375. THERMAL LINEAR EXPANSION OF SODIUM BORATE GLASS Na_2O-B_2O_3

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Na_2O	Composition (weight percent) B_2O_3	Composition (continued), Specifications, and Remarks
1	1086	Gooding, E. J. and Turner, W. E. S.	1934		273-569	26B	3.38	96.56	Raw materials mixed in melt; m.p. 1623 K; specimen annealed; reported error <1.5%.
2	1086	Gooding, E. J. and Turner, W. E. S.	1934		273-566	26C	2.36	97.66	Raw materials mixed in melt; m.p. 1623 K; specimen annealed; reported error <1.5%.
3	1086	Gooding, E. J. and Turner, W. E. S.	1934		273-566	26C	2.36	97.66	The above specimen, strained.
4	1086	Gooding, E. J. and Turner, W. E. S.	1934		273-604	25B	7.78	92.18	Raw materials mixed in melt; m.p. 1593 K; specimen annealed; reported error <1.5%.
5	1086	Gooding, E. J. and Turner, W. E. S.	1934		273-604	25B	7.78	92.18	The above specimen, strained.
6	1086	Gooding, E. J. and Turner, W. E. S.	1934		273-652	6B	11.43	88.56	Raw materials mixed in melt; m.p. 1563 K; specimen annealed; reported error <1.5%.
7	1086	Gooding, E. J. and Turner, W. E. S.	1934		273-756	1H	30.18	69.88	Raw materials mixed in melt; m.p. 1473 K; specimen annealed; reported error <1.5%.
8	1086	Gooding, E. J. and Turner, W. E. S.	1934		273-707	5B	15.80	84.22	Raw materials mixed in melt; m.p. 1573 K; specimen annealed; reported error <1.5%.
9	1086	Gooding, E. J. and Turner, W. E. S.	1934		273-699	5B	15.80	84.22	The above specimen, strained.
10	1086	Gooding, E. J. and Turner, W. E. S.	1934		273-744	4C	18.46	81.47	Raw materials mixed in melt; m.p. 1573 K; specimen annealed; reported error <1.5%.
11	1086	Gooding, E. J. and Turner, W. E. S.	1934		273-746	34	21.76	78.19	Raw materials mixed in melt; m.p. approx. 1523 K; specimen annealed; reported error <1.5%.
12	1086	Gooding, E. J. and Turner, W. E. S.	1934		273-742	34	21.76	78.19	The above specimen, strained.

DATA TABLE 375. THERMAL LINEAR EXPANSION OF SODIUM BORATE GLASS $Na_2O-B_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
273	-0.028
323	0.043
373	0.115
423	0.187
473	0.262
506	0.312
523	0.355
541	0.435
565	0.769
569	0.764

CURVE 2

T	$\Delta L/L_0$
273	-0.028*
323	0.043*
373	0.115*
423	0.187*
473	0.254
506	0.300
523	0.338
540	0.411
563	0.729
566	0.724

CURVE 3

T	$\Delta L/L_0$
273	-0.032
323	0.047*
373	0.116*
423	0.188*
435	0.202
459	0.209
473	0.205
500	0.178
523	0.110
533	0.095
545	0.152
562	0.310
566	0.312

CURVE 4

T	$\Delta L/L_0$
273	-0.023
323	0.034
373	0.094
423	0.147

CURVE 4 (cont.)

T	$\Delta L/L_0$
473	0.203*
523	0.265
557	0.318
567	0.342
573	0.379
598	0.657
601	0.660
604	0.659

CURVE 5

T	$\Delta L/L_0$
273	-0.024*
323	0.035*
373	0.092*
423	0.144*
473	0.191
523	0.225
553	0.240
573	0.300
581	0.361
600	0.584
604	0.586

CURVE 6

T	$\Delta L/L_0$
273	-0.019*
323	0.028
373	0.076
423	0.127
473	0.178
523	0.232
573	0.288
612	0.339
623	0.364
649	0.533
651	0.538
652	0.534

CURVE 7

T	$\Delta L/L_0$
273	-0.022*
323	0.033*
373	0.087
423	0.143*
473	0.199
523	0.262*

CURVE 7 (cont.)

T	$\Delta L/L_0$
573	0.330
623	0.403
673	0.475
723	0.558
741	0.614
753	0.681
756	0.677

CURVE 8

T	$\Delta L/L_0$
273	-0.018*
323	0.026*
373	0.069
423	0.116
473	0.163
523	0.210
573	0.265
623	0.323
673	0.389
687	0.430
700	0.510
703	0.514
707	0.512

CURVE 9

T	$\Delta L/L_0$
273	-0.020*
323	0.029*
373	0.069*
423	0.113*
473	0.161*
523	0.211*
573	0.255
608	0.270
623	0.263
653	0.259
673	0.268
694	0.318
699	0.319

CURVE 10

T	$\Delta L/L_0$
273	-0.018*
323	0.027*
373	0.077*
423	0.125*

CURVE 10 (cont.)

T	$\Delta L/L_0$
473	0.174*
523	0.226*
573	0.281*
623	0.342
673	0.396
705	0.439
723	0.468
739	0.510
744	0.510

CURVE 11

T	$\Delta L/L_0$
273	-0.018*
323	0.028*
373	0.076*
423	0.127*
473	0.173
523	0.226*
573	0.285
623	0.342*
673	0.407
723	0.485
732	0.510
742	0.552
746	0.554

CURVE 12

T	$\Delta L/L_0$
273	-0.018*
323	0.028*
373	0.077*
423	0.125*
473	0.177*
523	0.229*
573	0.284*
623	0.343*
673	0.384*
723	0.420
738	0.454
742	0.456

* Not shown in figure.

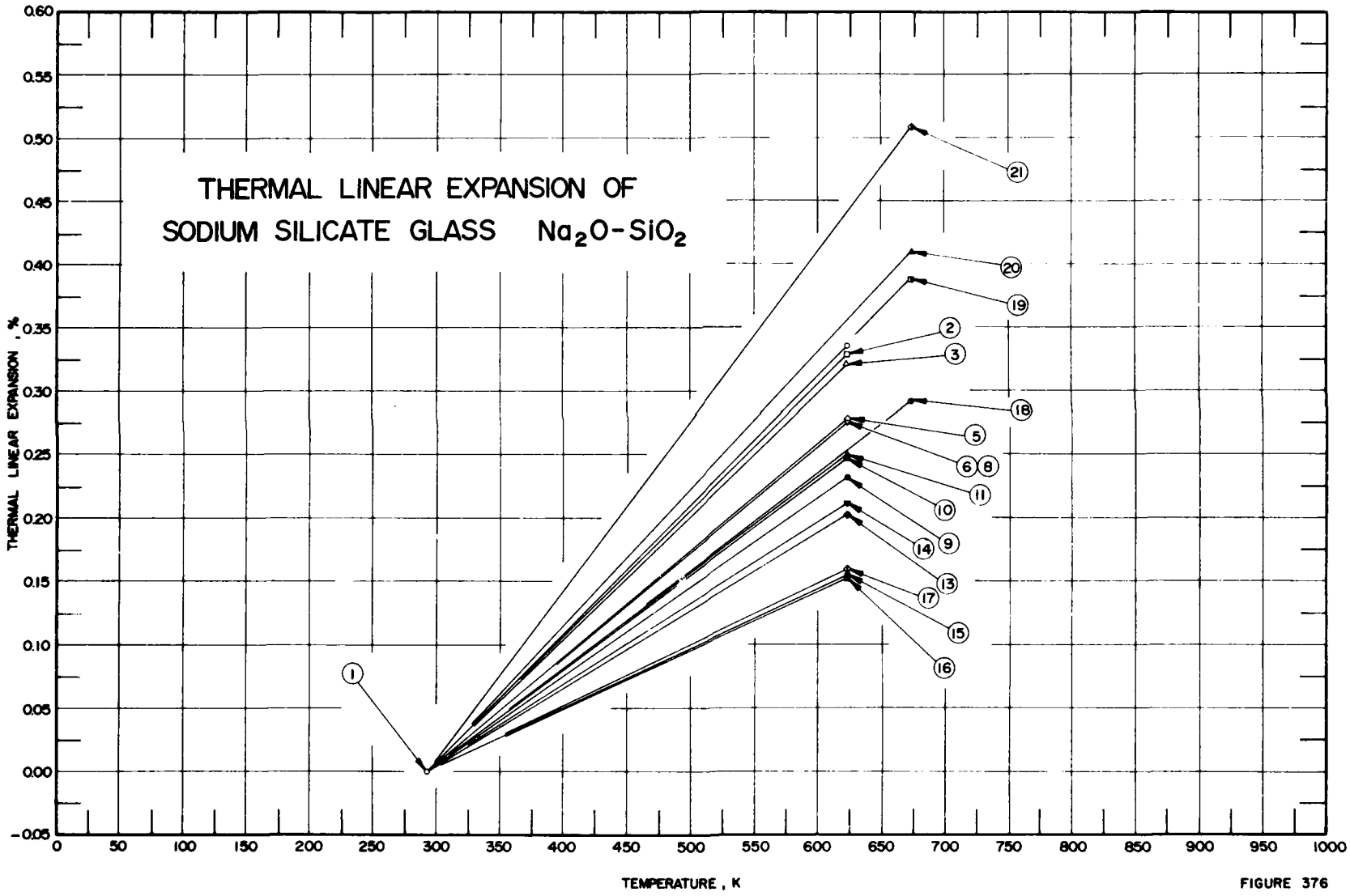

THERMAL LINEAR EXPANSION OF
SODIUM SILICATE GLASS Na_2O-SiO_2
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1
2
3
5
6
8
9
10
11
13
14
15
16
17
18
19
20
21

FIGURE 376

SPECIFICATION TABLE 376. THERMAL LINEAR EXPANSION OF SODIUM SILICATE GLASS Na_2O-SiO_2

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Na_2O	SiO_2	Composition (continued), Specifications, and Remarks
1	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		18.9	81.1	Specimen annealed 15 min at 798 K.
2	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		18.9	81.1	The above specimen, heat treated 8 hr at 873 K, to develop two phase structures where second phase is dispersed as particles in a continuous matrix phase (Type I).
3	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		18.1	81.9	Specimen annealed 15 min at 798 K.
4*	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		18.1	81.9	The above specimen, heat treated 8 hr at 873 K to develop two phase structure similar to the above Type I structure.
5	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		15.2	84.8	Specimen annealed 15 min at 753 K.
6	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		15.2	84.8	The above specimen, heat treated 8 hr at 873 K to develop two phase structure in which phases are independently interconnected (Type II structure).
7*	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		15.2	84.8	The above specimen, heat treated 4 hr at 953 K to produce Type I structure.
8	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		15.2	84.8	The above specimen, heat treated 4 hr at 983 K to produce Type I structure.
9	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		12.9	87.1	Specimen annealed 15 min at 773 K.
10	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		12.9	87.1	The above specimen, heat treated 8 hr at 873 K to produce Type I structure.
11	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		12.9	87.1	The above specimen, heat treated 4 hr at 923 K to obtain Type II structure.
12*	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		12.9	87.1	The above specimen, heat treated 1.5 hr at 1043 K to obtain Type I structure.
13	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		10.6	89.4	Specimen annealed 45 min at 778 K.
14	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		10.6	89.4	The above specimen, heat treated 8 hr at 873 K to obtain Type II structure.
15	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		7.4	92.6	Specimen annealed 15 min at 788 K.
16	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		7.4	92.6	The above specimen, heat treated 2 hr at 873 K to obtain Type II structure.
17	1095	Redwine, R. H. and Field, M. B.	1968	L	293,623		7.4	92.6	The above specimen, heat treated 8 hr at 873 K to obtain Type II structure.
18	1096	Vakhrameev, V. I. and Evstrop'ev, K. S.	1969	L	293,673		15.4	84.6	Chemically pure reagents melted in corundum crucibles and cast on steel plate; softening temperature 823 K.
19	1096	Vakhrameev, V. I. and Evstrop'ev, K. S.	1969	L	293,673		20.5	79.5	Similar to the above specimen; softening temperature 798 K.

* Not shown in figure.

SPECIFICATION TABLE 376. THERMAL LINEAR EXPANSION OF SODIUM SILICATE GLASS Na_2O-SiO_2 (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) Na_2O	SiO_2	Composition (continued), Specifications, and Remarks
20	1096	Vakhrameev, V.I. and Evstrop'ev, K.S.	1969	L	293,673		23.1	76.9	Similar to the above specimen; softening temperature 773 K.
21	1096	Vakhrameev, V.I. and Evstrop'ev, K.S.	1969	L	293,673		28.2	71.8	Similar to the above specimen; softening temperature 763 K.

DATA TABLE 376. THERMAL LINEAR EXPANSION OF SODIUM SILICATE GLASS Na_2O-SiO_2

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
623	0.335
CURVE 2	
293	0.000*
623	0.329
CURVE 3	
293	0.000*
623	0.321
CURVE 4*	
293	0.000
623	0.322
CURVE 5	
293	0.000*
623	0.277
CURVE 6	
293	0.000*
623	0.275
CURVE 7*	
293	0.000
623	0.276
CURVE 8	
293	0.000*
623	0.275
CURVE 9	
293	0.000*
623	0.232
CURVE 10	
293	0.000*
623	0.247
CURVE 11	
293	0.000*
623	0.249
CURVE 12*	
293	0.000
623	0.231
CURVE 13	
293	0.000*
623	0.202
CURVE 14	
293	0.000*
623	0.211
CURVE 15	
293	0.000*
623	0.155
CURVE 16	
293	0.000*
623	0.153
CURVE 17	
293	0.000*
623	0.159
CURVE 18	
293	0.000*
673	0.292
CURVE 19	
293	0.000*
673	0.388
CURVE 20	
293	0.000*
673	0.410
CURVE 21	
293	0.000*
673	0.509

* Not shown in figure.

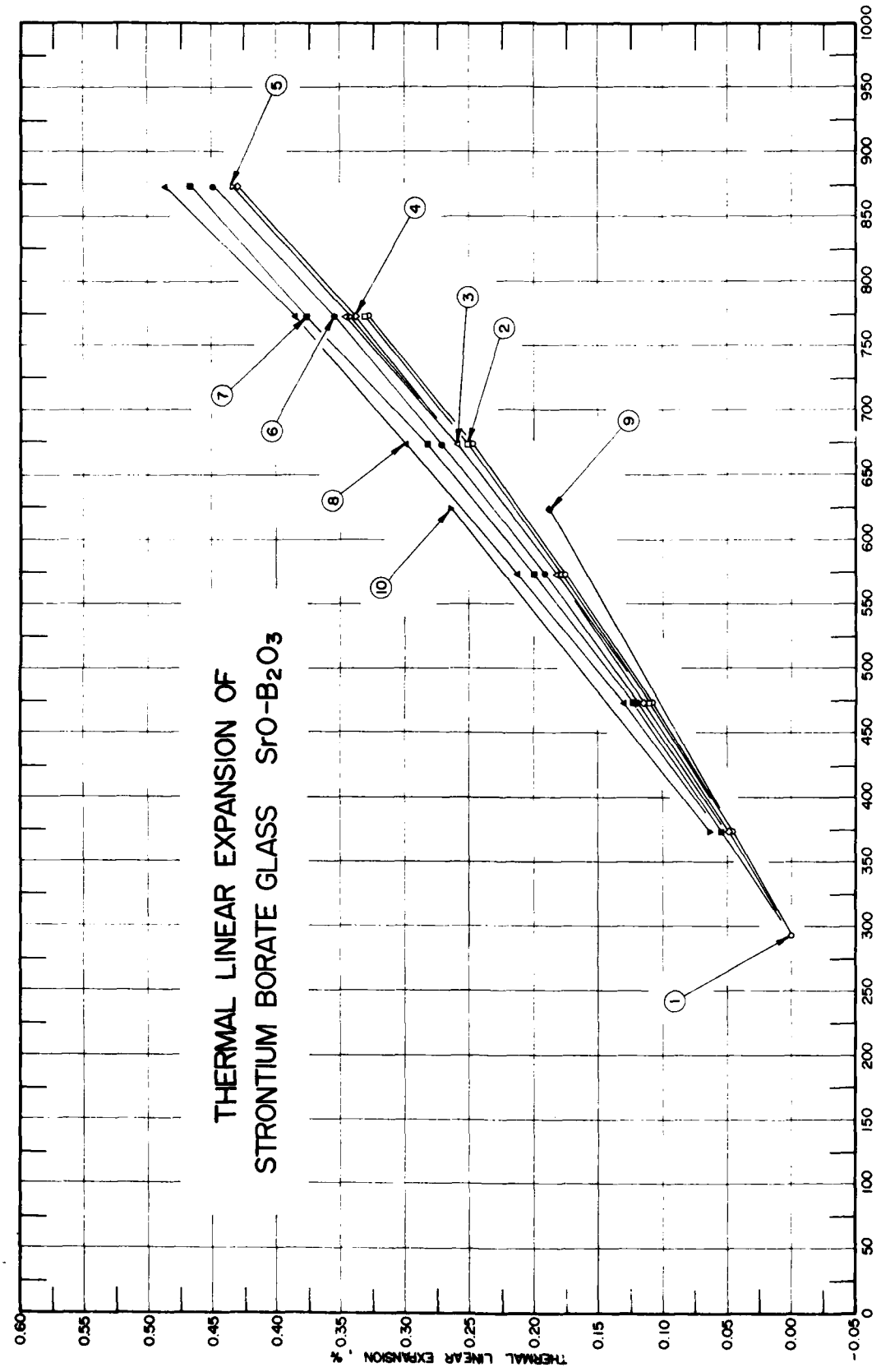

THERMAL LINEAR EXPANSION OF
STRONTIUM BORATE GLASS SrO-B2O3
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1
2
3
4
5
6
7
8
9
10

FIGURE 377

SPECIFICATION TABLE 377. THERMAL LINEAR EXPANSION OF STRONTIUM BORATE GLASS $SrO-B_2O_3$

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent) SrO	Composition (weight percent) B_2O_3	Composition (continued), Specifications, and Remarks
1	1082	Shermer, H. F.	1956	I	293-773		29.0	71.0	Sample cut from cylinder previously used for compressibility specimen; melting required amounts of reagent-grade chemicals in platinum crucibles at 1573 K; melts stirred until clear, poured onto a cold iron mold; annealed by holding them at 863 K for 3 hr and cooling at 3 C per hour for 30 hr; glasses allowed to cool to room temperature in furnace; heating rate for measurement 2 C/min.
2	1082	Shermer, H. F.	1956	I	293-773		29.4	70.6	Similar to the above specimen; density 2.677 g cm^{-3}; deformation temperature 894 K.
3	1082	Shermer, H. F.	1956	I	293-773		34.4	65.6	Similar to the above specimen; density 2.802 g cm^{-3}; deformation temperature 908 K.
4	1082	Shermer, H. F.	1956	I	293-873		35.5	64.5	Similar to the above specimen; density 2.852 g cm^{-3}; deformation temperature 911 K.
5	1082	Shermer, H. F.	1956	I	293-873		35.5	64.5	The above specimen; a remeasurement.
6	1082	Shermer, H. F.	1956	I	293-873		37.3	62.7	Similar to the above specimen; density 2.931 g cm^{-3}; deformation temperature 914 K.
7	1082	Shermer, H. F.	1956	I	293-873		39.6	60.4	Similar to the above specimen; density 3.007 g cm^{-3}; deformation temperature 922 K.
8	1082	Shermer, H. F.	1956	I	293-873		42.6	57.4	Similar to the above specimen; density 3.101 g cm^{-3}; deformation temperature 922 K.
9	1083	Hirayama, C.	1961	L	373,623		27.11	72.88	Specific gravity 2.65; annealed sample; sag point 581 C; reported error ±3%.
10	1083	Hirayama, C.	1961	L	373,623		38.94	61.06	Specific gravity 3.02; annealed sample; sag point 607 C; reported error ±3%.

DATA TABLE 377. THERMAL LINEAR EXPANSION OF STRONTIUM BORATE GLASS $SrO-B_2O_3$

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
373	0.046
473	0.108
573	0.175
673	0.247
773	0.328
CURVE 2	
293	0.000*
373	0.046*
473	0.110
573	0.177
673	0.251
773	0.330
CURVE 3	
293	0.000*
373	0.047*
473	0.111*
573	0.182
673	0.259
773	0.346
CURVE 4	
293	0.000*
373	0.048
473	0.114
573	0.182*
673	0.258*
773	0.339
873	0.430
CURVE 5	
293	0.000*
373	0.048*
473	0.113*
573	0.184*
673	0.261*
773	0.343
873	0.434
CURVE 6	
293	0.000*
373	0.051*
473	0.118
573	0.191
673	0.271
773	0.355
873	0.449
CURVE 7	
293	0.000*
373	0.054
473	0.123
573	0.200
673	0.283
773	0.376
873	0.466
CURVE 8	
293	0.000*
373	0.056*
473	0.130
573	0.213
673	0.298
773	0.385
873	0.486
CURVE 9	
373	0.045*
623	0.188
CURVE 10	
373	0.064
623	0.264

* Not shown in figure.

9. POLYMERS

SPECIFICATION TABLE 378. THERMAL LINEAR EXPANSION OF POLY(ACETYL TRIALLYL CITRATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	541	Acitelli, M.A., Grumby, W.L., and Naujokas, A.A.	1966	I	296-344		Sample suitably worked to form a tripod with legs 5.0 mm high; placed in furnace instrument.

DATA TABLE 378. THERMAL LINEAR EXPANSION OF POLY(ACETYL TRIALLYL CITRATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
296	0.019
313	0.130
344	0.423

* No figure given.

SPECIFICATION TABLE 379. THERMAL LINEAR EXPANSION OF POLYACRYLONITRILE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	542	Hayakawa, R., Nishi, T., Arisawa, K., and Wada, Y.	1967	V	293–402		Two specimens prepared: No. I by extracting dimethyl formamide solvent from a concentrated solution, then drying at 403 K; density 1.1776 g cm^{-3}; No. II by extracting NaCNS from solution in distilled water, then drying in vacuum at 363 K several hr; density 1.1863 g cm^{-3}; expansion data are results from both specimens.

DATA TABLE 379. THERMAL LINEAR EXPANSION OF POLYACRYLONITRILE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 1 (cont.)*	
293	0.000	371	0.597
295	0.016	374	0.634
299	0.032	381	0.705
303	0.067	385	0.740
306	0.110	389	0.784
313	0.135	392	0.844
317	0.171	396	0.937
321	0.190	402	1.018
327	0.210		
331	0.268		
335	0.290		
339	0.310		
340	0.338		
347	0.395		
352	0.418		
359	0.466		
362	0.497		
366	0.553		

* No figure given.

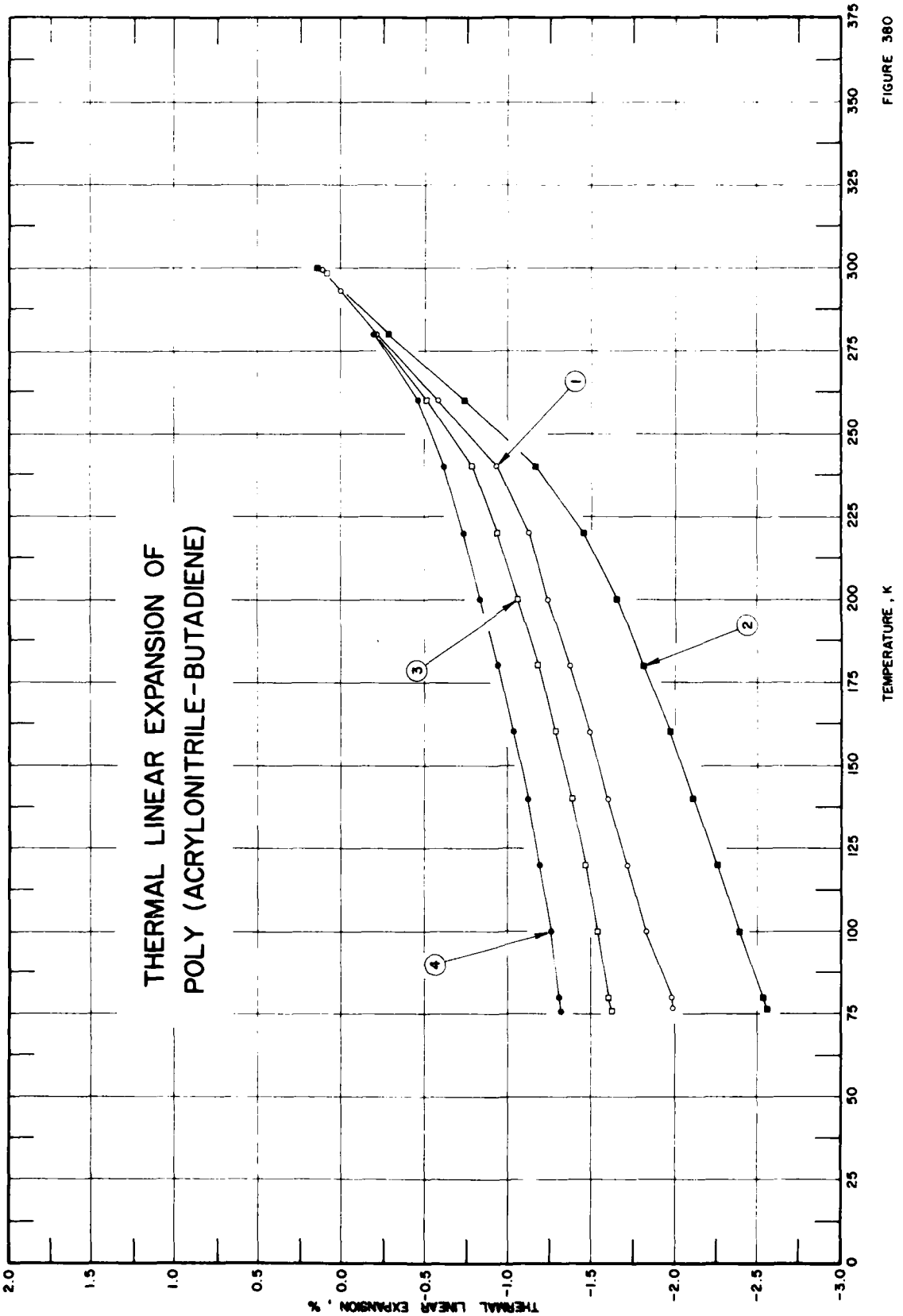

THERMAL LINEAR EXPANSION OF
POLY (ACRYLONITRILE-BUTADIENE)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
1
2
3
4

FIGURE 380

SPECIFICATION TABLE 380. THERMAL LINEAR EXPANSION OF POLY(ACRYLONITRILE-BUTADIENE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	538	Weitzel, D.N., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1963	L	77-299	II-21A	Paracril 18-80, from Naugatuck Chemical Co.; cured 20 min at 427 K; shore A hardness 75; zero-point correction of -0.117%.
2	538	Weitzel, D.N., et al.	1963	L	77-300	II-29D	Similar to the above specimen; shore A hardness 40; zero-point correction of -0.142%.
3	538	Weitzel, D.N., et al.	1963	L	76-298	II-21B	Hycar 1002, from B.F. Goodrich Chemical Co.; cured 20 min at 427 K; shore A hardness 75; zero-point correction of -0.087%.
4	538	Weitzel, D.N., et al.	1963	L	76-298	II-21C	Paracril D, from Naugatuck Chemical Co.; cured 20 min at 427 K; shore A hardness 85; zero-point correction of -0.087%.

DATA TABLE 380. THERMAL LINEAR EXPANSION OF POLY(ACRYLONITRILE-BUTADIENE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3		CURVE 4	
77	-1.985	77	-2.565	76	-1.622	76	-1.319
80	-1.962	80	-2.534	80	-1.606	80	-1.310
100	-1.846	100	-2.397	100	-1.538	100	-1.256
120	-1.718	120	-2.261	120	-1.469	120	-1.193
140	-1.600	140	-2.119	140	-1.389	140	-1.122
160	-1.487	160	-1.939	160	-1.293	160	-1.037
180	-1.372	180	-1.815	180	-1.177	180	-0.945
200	-1.247	200	-1.653	200	-1.064	200	-0.839
220	-1.125	220	-1.458	220	-0.944	220	-0.738
240	-0.931	240	-1.170	240	-0.778	240	-0.616
260	-0.581	260	-0.746	260	-0.517	260	-0.463
280	-0.204	280	-0.286	280	-0.206*	280	-0.190
293	0.000	293	0.000*	293	0.000*	293	0.000*
299	0.117	300	0.142	298	0.087	298	0.087*

* Not shown in figure.

SPECIFICATION TABLE 381. THERMAL LINEAR EXPANSION OF POLY(ALLYL DIGLYCOL CARBONATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	541	Achelli, M.A., Gumby, W.L., and Naujokas, A.A.	1966	I	295–407	CR-39	Sample suitably worked to form a tripod placed in furnace of instrument; specimen of specific gravity 1.154.

DATA TABLE 381. THERMAL LINEAR EXPANSION OF POLY(ALLYL DIGLYCOL CARBONATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
295	0.024
373	0.968
407	1.573

* No figure given.

SPECIFICATION TABLE 382. THERMAL LINEAR EXPANSION OF POLY(ALLYL METHACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	541	Acitelli, M.A., Gumby, W.L., and Naujokas, A.A.	1966	I	296-336		Sample suitably worked to form a tripod placed in furnace of instrument.

DATA TABLE 382. THERMAL LINEAR EXPANSION OF POLY(ALLYL METHACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
296	0.027
315	0.202
336	0.473

* No figure given.

SPECIFICATION TABLE 383. THERMAL LINEAR EXPANSION OF POLY(DIALLYL PHENYLPHOSPHONATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	541	Acitelli, M.A., Gumby, W.L., and Naujokas, A.A.	1966	I	296-327		Sample suitably worked to form a tripod in furnace of instrument.

DATA TABLE 383. THERMAL LINEAR EXPANSION OF POLY(DIALLYL PHENYLPHOSPHONATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
296	0.028
306	0.122
327	0.425

* No figure given.

SPECIFICATION TABLE 384. THERMAL LINEAR EXPANSION OF POLY(DIALLYL PHTHALATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	541	Achelli, M.A., Gumby, W.L., and Naujokas, A.A.	1966	I	296-343		Sample suitably worked to form a tripod placed in furnace of instrument.

DATA TABLE 384. THERMAL LINEAR EXPANSION OF POLY(DIALLYL PHTHALATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
296	0.021
313	0.140
343	0.415

* No figure given.

SPECIFICATION TABLE 385. THERMAL LINEAR EXPANSION OF POLY(TRIALLYL CITRATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	541	Acitelli, M.A., Gumby, W.L., and Naujokas, A.A.	1966	I	294-330		Sample suitably worked to form a tripod placed in furnace of instrument.

DATA TABLE 385. THERMAL LINEAR EXPANSION OF POLY(TRIALLYL CITRATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
294	0.005
311	0.093
330	0.229

* No figure given.

SPECIFICATION TABLE 386. THERMAL LINEAR EXPANSION OF AROMATIC POLYAMIDE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	538	Weltzel, D.H., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1963	L	80-300	HT-1	No details given.

DATA TABLE 386. THERMAL LINEAR EXPANSION OF AROMATIC POLYAMIDE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
80	-0.376
100	-0.347
120	-0.317
140	-0.293
160	-0.268
180	-0.230
200	-0.183
220	-0.143
240	-0.102
260	-0.061
280	-0.024
293	0.000
300	0.012

* No figure given.

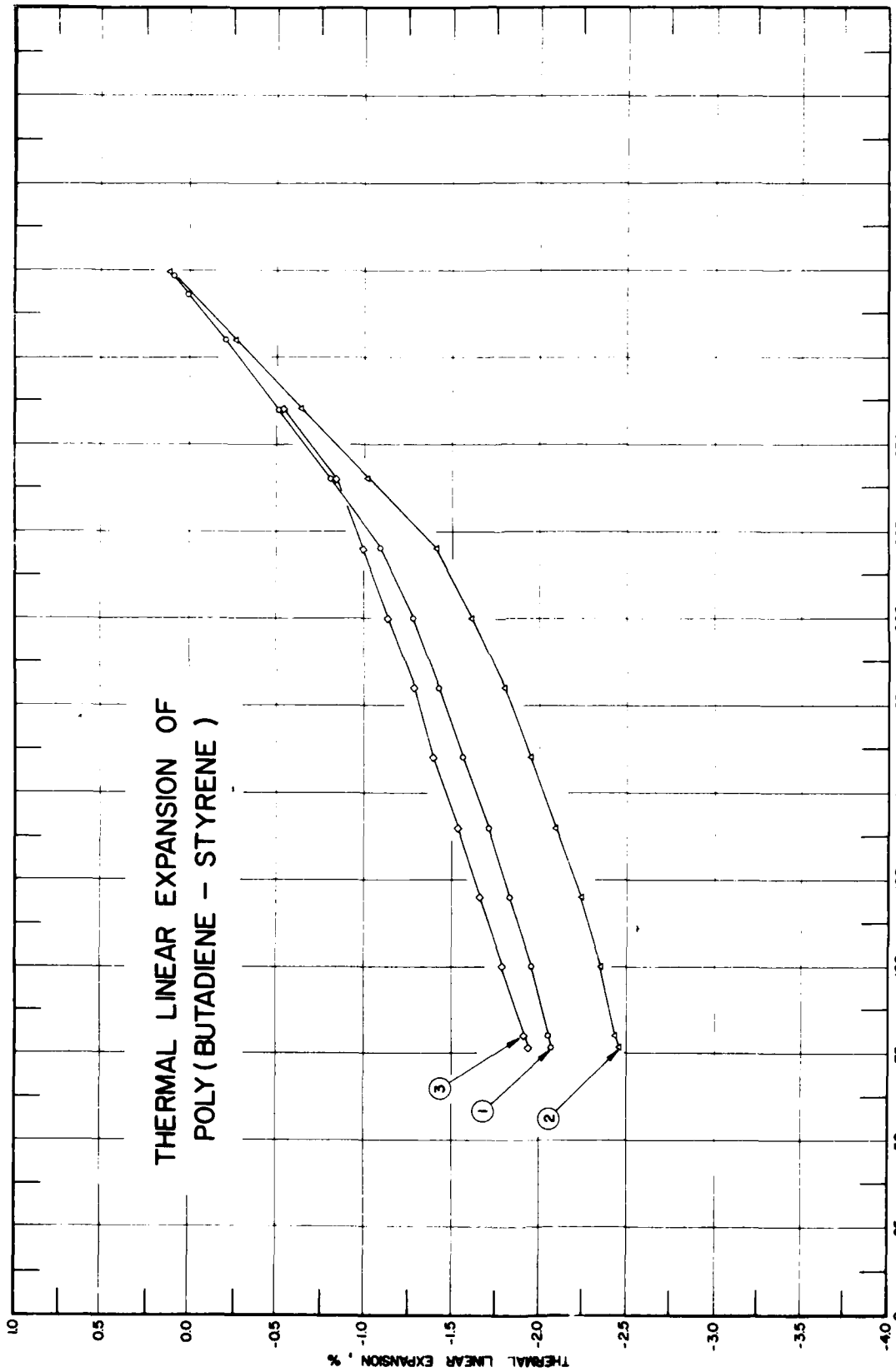

THERMAL LINEAR EXPANSION OF
POLY(BUTADIENE - STYRENE)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
1
2
3

FIGURE 387

SPECIFICATION TABLE 387. THERMAL LINEAR EXPANSION OF POLY(BUTADIENE-STYRENE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	538	Weitzel, D.N., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1966	L	77-298	II-21D	Synpol 1000 from Texas-U.S. Chemical Co.; cured 50 min at 433 K; shore A hardness 65.
2	538	Weitzel, D.N., et al.	1966	L	77-299	II-29E	Similar to the above specimen; cured 30 min at 427 K; shore A hardness 40.
3	538	Weitzel, D.N., et al.	1966	L	77-299	II-21E	Synpol 1013 from Texas-U.S. Chemical Co.; cured 50 min at 433 K; shore A hardness 70.

DATA TABLE 387. THERMAL LINEAR EXPANSION OF POLY(BUTADIENE-STYRENE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3	
77	-2.069	77	-2.458	77	-1.946
80	-2.053	80	-2.442	80	-1.920
100	-1.960	100	-2.356	100	-1.793
120	-1.835	120	-2.241	120	-1.665
140	-1.702	140	-2.099	140	-1.534
160	-1.570	160	-1.950	160	-1.399
180	-1.427	180	-1.800	180	-1.278
200	-1.277	200	-1.617	200	-1.137
220	-1.096	220	-1.410	220	-0.994
240	-0.808	240	-1.014	240	-0.826
260	-0.509	260	-0.636	260	-0.531
280	-0.206	280	-0.255	280	-0.204*
293	0.000	293	0.000*	293	0.000*
298	0.087	299	0.117	299	0.117*

* Not shown in figure.

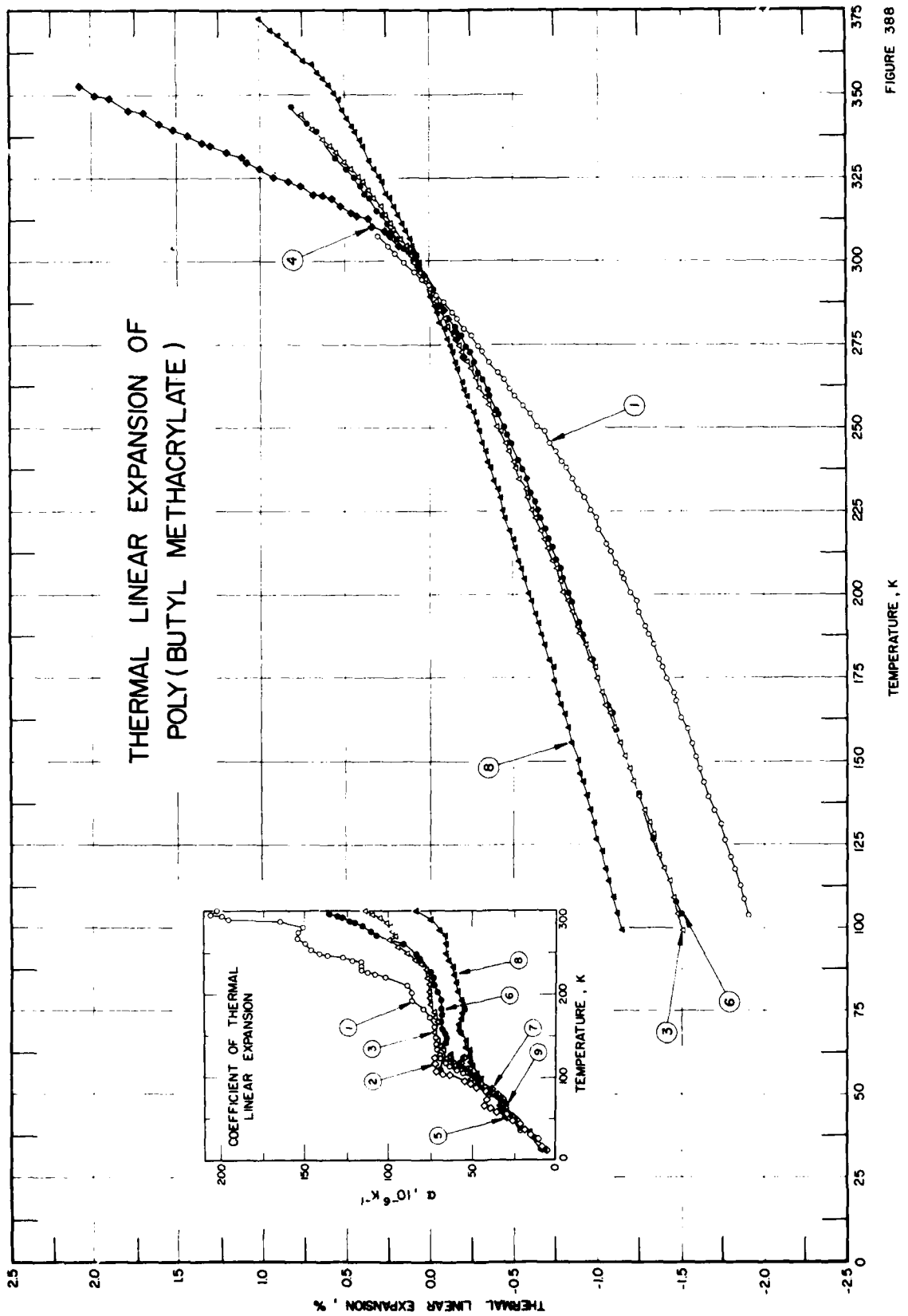

THERMAL LINEAR EXPANSION OF
POLY(BUTYL METHACRYLATE)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
α ,10⁻⁶K⁻¹
TEMPERATURE , K

FIGURE 388

SPECIFICATION TABLE 388. THERMAL LINEAR EXPANSION OF POLY(BUTYL METHACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	543	Haldon, R.A. and Simha, R.	1968	V	104-308	PnBMA	Poly(n-butyl methacrylate); specimen 0.25 in. diameter, 1.0 in. long; ends of cylinder filed flat stored in vacuum; molded in compression mold at 438 K and 500 psi; annealed at about 293 K prior to measurement; obtained from Dr. D. L. Glusker of Rohm and Haas Co.
2*	544	Haldon, R.A. and Simha, R.	1968	L	18-122		Poly(n-butyl methacrylate); this curve is here reported using the first given temperature (18 K) as reference temperature at which $\Delta L/L_0 = 0$.
3	543	Haldon, R.A. and Simha, R.	1968	V	99-344	PiBMA	Poly(iso-butyl methacrylate); specimen 0.25 in. diameter, 1.0 in. long; obtained from Dr. M.C. Shen of North American Aviation Science Center; ends of cylinder filed flat, stored in vacuum.
4	545	Morita, E., Kono, R., and Yoshizaki, H.	1968	I	272-353	PiBMA	Poly(iso-butyl methacrylate); sample prepared by bulk polymerization from a purified monomer; original plate of 0.5 cm thick; annealed and cut out into specimen plate; glass transition temperature Tg 309.7 K.
5*	544	Haldon, R.A. and Simha, R.	1968	L	13-129	PiBMA	Poly(iso-butyl methacrylate); this curve is here reported using the first given temperature (13 K) as reference temperature at which $\Delta L/L_0 = 0$.
6	543	Haldon, R.A. and Simha, R.	1968	V	104-347	PsBMA	Poly(sec-butyl methacrylate); specimen 0.25 in. diameter, 1.0 in. long; ends of cylinder filed flat, stored in vacuum; obtained from Dr. M.C. Shen of North American Aviation Science Center.
7*	544	Haldon, R.A. and Simha, R.	1968	L	12-121	PsBMA	Poly(sec-butyl methacrylate); this curve is here reported using the first given temperature (12 K) as reference temperature at which $\Delta L/L_0 = 0$.
8	543	Haldon, R.A. and Simha, R.	1968	V	99-373	PtBMA	Poly(tert-butyl methacrylate); specimen 0.25 in. diameter, 1.0 in. long; obtained from Dr. M.C. Shen of North American Aviation Science Center; ends of cylinder filled flat, stored in vacuum.
9*	544	Haldon, R.A. and Simha, R.	1968	L	32-105	PtBMA	Poly(tert-butyl methacrylate); this curve is here reported using the first given temperature (32 K) as reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

DATA TABLE 388. THERMAL LINEAR EXPANSION OF POLY(BUTYL METHACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1‡		CURVE 1 (cont.)‡		CURVE 2 (cont.)*, †, ‡		CURVE 3 (cont.)‡		CURVE 3 (cont.)‡		CURVE 4 (cont.)	
104	-1.91	257	-0.57	92	0.225	211	-0.73	326	0.42	323	0.743*
109	-1.88	260	-0.52	95	0.238	214	-0.71	328	0.46	323	0.773
113	-1.86	262	-0.48	97	0.249	217	-0.69	330	0.50	324	0.799*
118	-1.83	265	-0.45	99	0.262	219	-0.67	333	0.55	324	0.830
123	-1.80	267	-0.41	102	0.281	223	-0.64	335	0.58	325	0.851*
127	-1.76	270	-0.36	104	0.295	226	-0.62	337	0.63	326	0.884*
132	-1.73	273	-0.32	107	0.317	229	-0.59	340	0.69	326	0.916
136	-1.70	275	-0.29	111	0.340	232	-0.58	344	0.76	328	0.975*
140	-1.67	278	-0.25	113	0.357	235	-0.54			328	1.000
144	-1.64	280	-0.21	116	0.377	238	-0.52	CURVE 4		330	1.050*
148	-1.61	283	-0.17	118	0.389	240	-0.51			330	1.080
152	-1.58	285	-0.14	122	0.420	243	-0.48	272	-0.204	332	1.120
156	-1.56	288	-0.09			246	-0.46	275	-0.194	332	1.150*
160	-1.53	290	-0.05	CURVE 3‡		249	-0.43	277	-0.169	332	1.170*
163	-1.50	293	0.00			251	-0.41	279	-0.159	333	1.200
167	-1.47	295	0.04	99	-1.51	254	-0.39	283	-0.111	335	1.270*
171	-1.45	297	0.09	104	-1.49	257	-0.36	286	-0.092	335	1.300
175	-1.42	300	0.15	109	-1.46	259	-0.34	287	-0.074	336	1.320*
178	-1.39	303	0.20	114	-1.43	262	-0.30	290	-0.050*	336	1.350
181	-1.37	305	0.25	118	-1.40	265	-0.28	292	-0.025	337	1.380*
185	-1.34	308	0.31	123	-1.37	268	-0.25	293	0.000*	338	1.400*
188	-1.31			128	-1.34	270	-0.23	296	0.029	338	1.430
191	-1.29	CURVE 2*, †, ‡		132	-1.31	273	-0.20	298	0.057	339	1.460*
195	-1.25			136	-1.28	275	-0.18	301	0.084	340	1.500*
198	-1.23	18	0.000	140	-1.25	278	-0.15	303	0.100	340	1.520
201	-1.20	25	0.007	144	-1.22	281	-0.12	304	0.138*	341	1.550*
205	-1.17	30	0.014	148	-1.20	283	-0.10	305	0.177	342	1.580*
207	-1.15	37	0.026	152	-1.17	286	-0.07	308	0.229	342	1.610
210	-1.12	43	0.037	156	-1.14	288	-0.05	309	0.260	343	1.640*
213	-1.09	47	0.047	160	-1.11	291	-0.03	310	0.288*	344	1.670*
216	-1.06	51	0.057	164	-1.08	292	-0.01	311	0.311*	345	1.700
220	-1.03	55	0.069	167	-1.06	295	0.02	311	0.342	345	1.730*
223	-1.00	58	0.081	171	-1.03	297	0.05	313	0.365	346	1.760*
226	-0.96	62	0.092	175	-1.00	300	0.08	313	0.403*	346	1.790
229	-0.93	65	0.109	178	-0.98	302	0.10	314	0.430	347	1.820*
232	-0.89	68	0.120	182	-0.96	305	0.13	315	0.462	348	1.870*
235	-0.86	72	0.135	185	-0.93	307	0.17	316	0.487*	349	1.900
238	-0.82	75	0.149	188	-0.90	310	0.21	317	0.518	349	1.940*
240	-0.79	78	0.162	191	-0.88	312	0.23	317	0.545*	350	1.980
243	-0.76	82	0.177	195	-0.86	314	0.26	319	0.573	351	2.010*
246	-0.72	84	0.187	198	-0.83	317	0.29	319	0.596*	352	2.050*
249	-0.69	87	0.199	201	-0.80	319	0.33	320	0.629	353	2.080
251	-0.65	88	0.205	204	-0.78	322	0.36	320	0.653*		
254	-0.61	89	0.209	208	-0.76	324	0.39	321	0.683		

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 388. THERMAL LINEAR EXPANSION OF POLY(BUTYL METHACRYLATE) (continued)

T	$\Delta L/L_0$
CURVE 5*, †, ‡	
13	0.000
18	0.005
25	0.013
32	0.023
37	0.034
42	0.044
47	0.056
50	0.066
54	0.078
58	0.091
61	0.102
65	0.113
68	0.126
72	0.138
75	0.147
78	0.159
81	0.172
83	0.181
87	0.195
90	0.209
92	0.219
95	0.233
98	0.247
100	0.256
103	0.273
106	0.284
108	0.299
110	0.310
113	0.326
116	0.346
121	0.372
123	0.385
125	0.398
129	0.426
CURVE 6‡	
104	-1.50
109	-1.46
114	-1.43*
118	-1.40*
122	-1.36*
127	-1.33
132	-1.30*
136	-1.27*
141	-1.24
144	-1.22*

T	$\Delta L/L_0$
CURVE 6 (cont.)‡	
148	-1.19*
152	-1.16*
156	-1.14*
159	-1.11
164	-1.09
167	-1.06
171	-1.04*
175	-1.01*
178	-0.99*
181	-0.97
185	-0.94*
188	-0.92
192	-0.89
195	-0.86*
198	-0.85
201	-0.83
205	-0.80
208	-0.78
211	-0.76
214	-0.73
217	-0.71
220	-0.69
223	-0.67
226	-0.65
228	-0.63
231	-0.61
235	-0.58
238	-0.56
241	-0.53
242	-0.52*
246	-0.49
248	-0.47
251	-0.45
254	-0.42
256	-0.40
260	-0.37
262	-0.35
265	-0.32
267	-0.29
270	-0.27
273	-0.24
275	-0.21
278	-0.18
281	-0.15
283	-0.12*
286	-0.09*
288	-0.06*

T	$\Delta L/L_0$
CURVE 6 (cont.)‡	
290	-0.04*
292	-0.02*
295	0.03*
297	0.06*
300	0.09*
302	0.12*
304	0.15
307	0.19
309	0.22
312	0.25
314	0.28
316	0.31
319	0.35
321	0.38
323	0.41
326	0.45
328	0.49
330	0.52*
333	0.56
335	0.60*
337	0.64*
339	0.67
342	0.73
344	0.77*
347	0.82
CURVE 7*, †, ‡	
12	0.000
18	0.004
25	0.010
32	0.019
37	0.028
42	0.039
47	0.051
51	0.060
55	0.070
58	0.080
62	0.092
65	0.102
69	0.114
72	0.125
76	0.137
78	0.146
81	0.157
85	0.169
87	0.177

T	$\Delta L/L_0$
CURVE 7 (cont.)*, †, ‡	
89	0.188
92	0.202
95	0.217
98	0.231
101	0.246
104	0.259
106	0.270
109	0.285
111	0.297
113	0.309
116	0.325
118	0.335
121	0.351
CURVE 8‡	
99	-1.15
104	-1.12
109	-1.10
114	-1.07
118	-1.05
123	-1.03
127	-1.00
132	-0.98
136	-0.96
140	-0.94
144	-0.92
147	-0.90
151	-0.88
156	-0.85
160	-0.83
164	-0.81
167	-0.78
170	-0.77
174	-0.74
178	-0.73
181	-0.71
185	-0.69
188	-0.67
192	-0.65
194	-0.63
198	-0.61
201	-0.59
205	-0.57
208	-0.55
211	-0.53
214	-0.52

T	$\Delta L/L_0$
CURVE 8 (cont.)‡	
217	-0.50
219	-0.48
223	-0.46
226	-0.44
229	-0.43
232	-0.41
234	-0.39
238	-0.37
240	-0.35
243	-0.34
246	-0.32
249	-0.30
252	-0.28
255	-0.26
257	-0.24
260	-0.23
262	-0.21
264	-0.20
268	-0.17
270	-0.16
273	-0.14
275	-0.13
277	-0.11
280	-0.09
282	-0.07
285	-0.06
287	-0.04
290	-0.02
293	0.00*
295	0.02*
297	0.04*
300	0.06
302	0.08
305	0.10
307	0.12
309	0.14
312	0.16
314	0.18
317	0.21
319	0.23
321	0.26
324	0.28
326	0.30
328	0.33
331	0.36
335	0.39
337	0.41

T	$\Delta L/L_0$
CURVE 8 (cont.)‡	
339	0.44
341	0.46
343	0.48
346	0.51
348	0.54
351	0.57
353	0.60
355	0.63
357	0.67
359	0.69
361	0.75
363	0.80
366	0.84
368	0.89
370	0.94
373	1.00
CURVE 9*, †, ‡	
32	0.000
37	0.010
42	0.021
46	0.032
50	0.042
54	0.053
57	0.064
61	0.078
64	0.087
68	0.097
71	0.108
74	0.118
77	0.131
80	0.142
84	0.157
86	0.168
89	0.179
92	0.195
95	0.210
97	0.217
99	0.229
102	0.245
105	0.259

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 388. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(BUTYL METHACRYLATE)

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
104	56.6
109	59.6
113	64.0
118	66.3
123	68.3
127	69.4
132	70.9
136	71.8*
140	71.8
144	71.8*
148	71.8
152	72.5*
156	70.9*
160	72.5
163	73.4*
167	74.7*
171	75.3
175	76.4*
178	78.5*
181	79.7
185	82.8*
188	85.3*
191	86.8
195	86.8*
198	86.8*
201	86.8
205	87.5*
207	88.6*
210	88.6
213	90.1*
216	95.0*
220	102.2
223	107.9
226	112.5
229	116.2
232	116.2
235	116.2*
238	116.2
240	122.0
243	127.3
246	136.5
249	141.6
251	145.8
254	147.6*
257	148.4*

T	α
CURVE 1 (cont.)‡	
260	149.7
262	150.1*
265	152.9*
267	154.1
270	155.1*
273	153.8
275	152.0*
278	151.1*
280	150.7
283	151.1*
285	154.1*
288	164.5
290	195.0
293	196.6
295	206.1
297	204.9*
300	202.2
303	201.4*
305	200.5*
308	199.6*
CURVE 2‡	
18	8.5
25	11.9
30	15.3
37	18.9
43	21.5
47	26.3
51	26.8*
55	30.0
58	35.8
62	39.0
65	42.4
68	42.4*
72	41.7
75	42.3*
78	41.0*
82	42.4
84	42.4*
87	43.7*
88	45.7*
89	47.8
92	51.5
95	54.6

T	α
CURVE 2 (cont.)‡	
97	56.3*
99	58.0*
102	64.4
104	68.1
107	71.9
111	73.2*
113	73.2*
116	73.2
118	71.5*
122	73.4
CURVE 3‡	
99	51.3
104	54.4
109	57.7
114	61.5
118	64.1
123	65.9
128	67.3*
132	67.3
136	69.6
140	69.6*
144	71.6
148	72.9*
152	72.9
156	72.5*
160	73.8*
164	73.8*
167	70.9
171	72.3
175	71.9*
178	73.1
182	73.8*
185	75.0*
188	75.0
191	75.6*
195	75.2
198	75.2*
201	75.2
204	75.2*
208	75.3*
211	75.6
214	75.6*
217	77.2*

T	α
CURVE 3 (cont.)‡	
219	77.2
223	77.3*
226	77.3*
229	77.4
232	79.4*
235	80.8
238	81.9*
240	84.1
243	84.1*
246	86.0*
249	88.2
251	90.0*
254	91.7*
257	94.6
259	97.6*
262	99.0*
265	99.0
268	97.8*
270	96.0
273	96.0*
275	97.4
278	96.7*
281	98.3
283	100.5*
286	101.5
288	103.4*
291	105.4
292	107.2*
295	110.5
297	112.8*
300	114.8
302	117.5*
305	121.4*
307	126.9*
310	129.2*
312	131.4*
314	132.9*
317	133.6*
319	136.9*
322	143.2*
324	150.7*
326	158.0*
328	170.9*
330	180.2*
333	192.0*

T	α
CURVE 3 (cont.)‡	
335	196.6*
337	199.1*
340	195.5*
344	192.8*
CURVE 5‡	
13	9.3
18	9.2*
25	13.4
32	17.0
37	20.8*
42	23.4*
47	27.4*
50	30.4
54	31.4*
58	33.2
61	33.2*
65	34.0
68	34.0*
72	34.3
75	35.0*
78	37.4
81	40.1*
83	41.7*
87	44.4
90	45.8*
92	46.7
95	46.7*
98	47.4
100	47.4*
103	48.2*
106	52.1
108	55.1*
110	57.8
113	60.1*
116	62.4*
121	63.1
123	61.9*
125	63.3*
129	63.3
CURVE 6‡	
104	69.7*

T	α
CURVE 6 (cont.)‡	
109	69.7
114	71.6*
118	71.6*
122	71.4*
127	70.2*
132	68.1*
136	66.9*
141	66.2
144	66.2*
148	65.4
152	66.9
156	67.7*
159	67.7
164	68.3*
167	68.9
171	68.9*
175	68.1
178	68.1*
181	68.1
185	69.8*
188	69.8*
192	68.1
195	68.3*
198	69.6*
201	70.3
205	71.4*
208	71.9*
211	72.4
214	71.4*
217	72.9*
220	73.7
223	73.7*
226	75.1*
228	76.4
231	77.1*
235	78.8*
238	80.2*
241	81.7
242	83.8*
246	83.1*
248	83.1
251	85.6*
254	86.3*
256	88.9*
260	91.6

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 388. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(BUTYL METHACRYLATE) (continued)

T	α
CURVE 6 (cont.)‡	
262	95.2*
265	99.9*
267	104.0*
270	107.1
272	109.4*
275	111.0
278	114.1*
281	115.7
283	116.8*
286	120.2
288	123.1
290	125.7*
292	127.6
295	131.7
297	136.0
300	136.0*
302	135.2*
304	136.1*
307	137.8*
309	135.7*
312	137.1*
314	136.6*
316	134.8*
319	132.2*
321	134.1*
323	140.0*
326	146.7*
328	156.2*
330	166.5*
333	177.7*
335	180.9*
337	183.6*
339	185.6*
342	185.6*
344	185.2*
347	185.2*
CURVE 7‡	
12	6.2
18	6.3*
25	11.7*
32	15.5*
37	18.9*
42	22.6*
47	24.3
51	26.6

T	α
CURVE 7 (cont.)‡	
55	26.6*
58	29.9*
62	31.1
65	32.5*
69	33.7*
72	32.5
76	32.7*
78	35.1
81	38.0*
85	38.0
87	40.5*
89	43.1*
92	46.2*
95	50.3*
98	51.6*
101	51.6*
104	50.3*
106	51.6*
109	52.3*
111	53.0*
113	55.1*
116	57.1*
118	57.1
121	55.4
CURVE 8‡	
99	44.7
104	47.4
109	48.8*
114	49.3
118	51.6
123	50.5*
127	51.4
132	51.4
136	53.0
140	53.1*
144	53.6
147	54.9*
151	56.9
156	57.4
160	57.4*
164	57.8
167	57.8*
170	56.7
174	55.9*
178	56.4

T	α
CURVE 8 (cont.)‡	
181	54.9
185	55.5
188	57.3*
192	56.4
194	57.7*
198	57.7*
201	58.4
205	58.4*
208	59.0*
211	59.0*
214	59.0
217	60.3*
219	60.7*
223	61.5
226	61.5*
229	61.5*
232	62.0
234	62.8*
238	62.8*
240	64.4
243	65.3*
246	65.3*
249	65.3
252	66.9*
255	65.7*
257	65.7*
260	65.7
262	66.4*
264	66.9*
268	66.6*
270	66.6
273	68.0*
275	68.9*
277	68.9
280	69.3*
282	69.3*
285	70.7*
287	72.5*
290	75.0
293	78.8*
295	80.1*
297	81.4*
300	83.9
302	85.3*
305	86.2*
307	89.7*
309	91.3*

T	α
CURVE 8 (cont.)‡	
312	94.2*
314	97.7*
317	98.9*
319	99.8*
321	99.8*
324	99.8*
326	99.3*
328	99.3*
331	99.5*
335	101.1*
337	102.0*
339	102.7*
341	104.3*
343	108.0*
346	113.7*
348	118.8*
351	127.8*
353	144.5*
355	164.5*
357	179.5*
359	205.5*
361	210.9*
363	212.4*
366	211.3*
368	211.3*
370	212.4*
373	214.4*
CURVE 9‡	
32	18.2*
37	21.1
42	23.9*
46	26.5*
50	29.0*
54	30.6*
57	32.3*
61	32.3*
64	31.0*
68	30.6
71	33.3*
74	35.3*
77	39.1
80	41.2*
84	42.9*
86	43.9*
89	45.6*

T	α
CURVE 9 (cont.)‡	
92	47.6*
95	47.6
97	49.3*
99	50.2*
102	50.2*
105	51.0*

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 389. THERMAL LINEAR EXPANSION OF POLYISOBUTYLENE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	546	Eichinger, B.E. and Flory, P.J.	1968	L	273-423	Enjay Vistanex LMMS	Specimen fractionated from 1% solution in benzene at 28 C using methanol as precipitant.

DATA TABLE 389. THERMAL LINEAR EXPANSION OF POLYISOBUTYLENE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*,‡	
273	-1.117
298	0.265
323	1.659
373	4.479
423	7.342

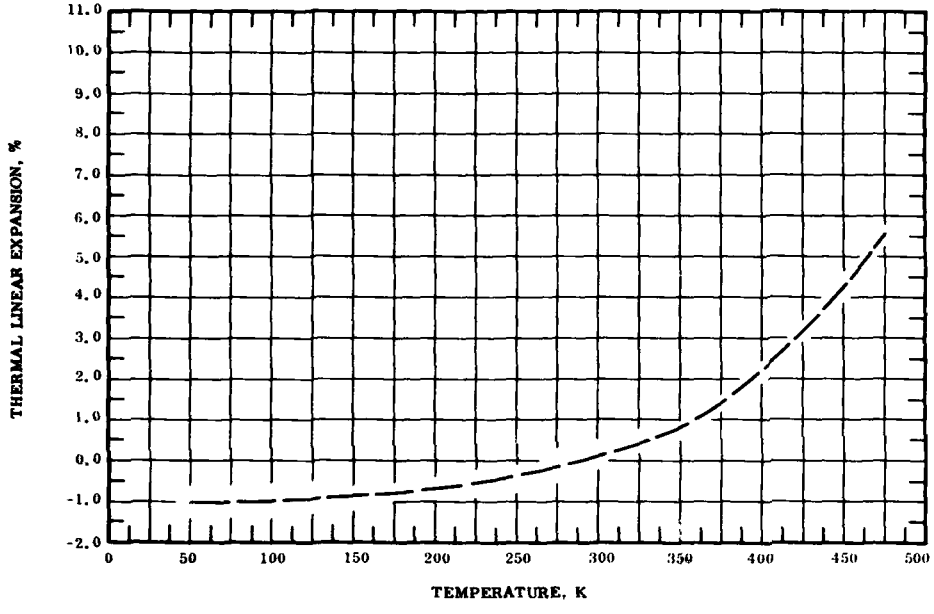
DATA TABLE 389. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLYISOBUTYLENE

[Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\ K^{-1}$]

T	α
CURVE 1*,‡	
273	551.0
298	555.0
323	560.0
373	568.0
423	577.0

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 390R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF POLYCARBONATE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
50	-1.000	2
75	-0.988	5
125	-0.927	17
150	-0.878	25
175	-0.810	35
200	-0.710	46
250	-0.415	77
275	-0.190	98
293	0.000	113
325	0.405	160
350	0.800	210
375	1.402	267
400	2.204	335
425	3.183	407
450	4.319	483
475	5.593	565

REMARKS

The provisional values are based on the selected experimental data (curves 2 and 4). The amorphous sample has higher thermal expansion as shown by curve 3. These values are considered accurate to within ±7% and are represented approximately by the following equations:

$$\Delta L/L_0 = -1.069 + 1.690 \times 10^{-3} T - 1.266 \times 10^{-5} T^2 + 6.602 \times 10^{-8} T^3 \quad (50\text{–}350\ K)$$

$$\Delta L/L_0 = 24.5 - 0.182\ T + 4.032 \times 10^{-4} T^2 - 2.176 \times 10^{-7} T^3 \quad (350\text{–}475\ K)$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equations and are considered accurate to about ±10%.

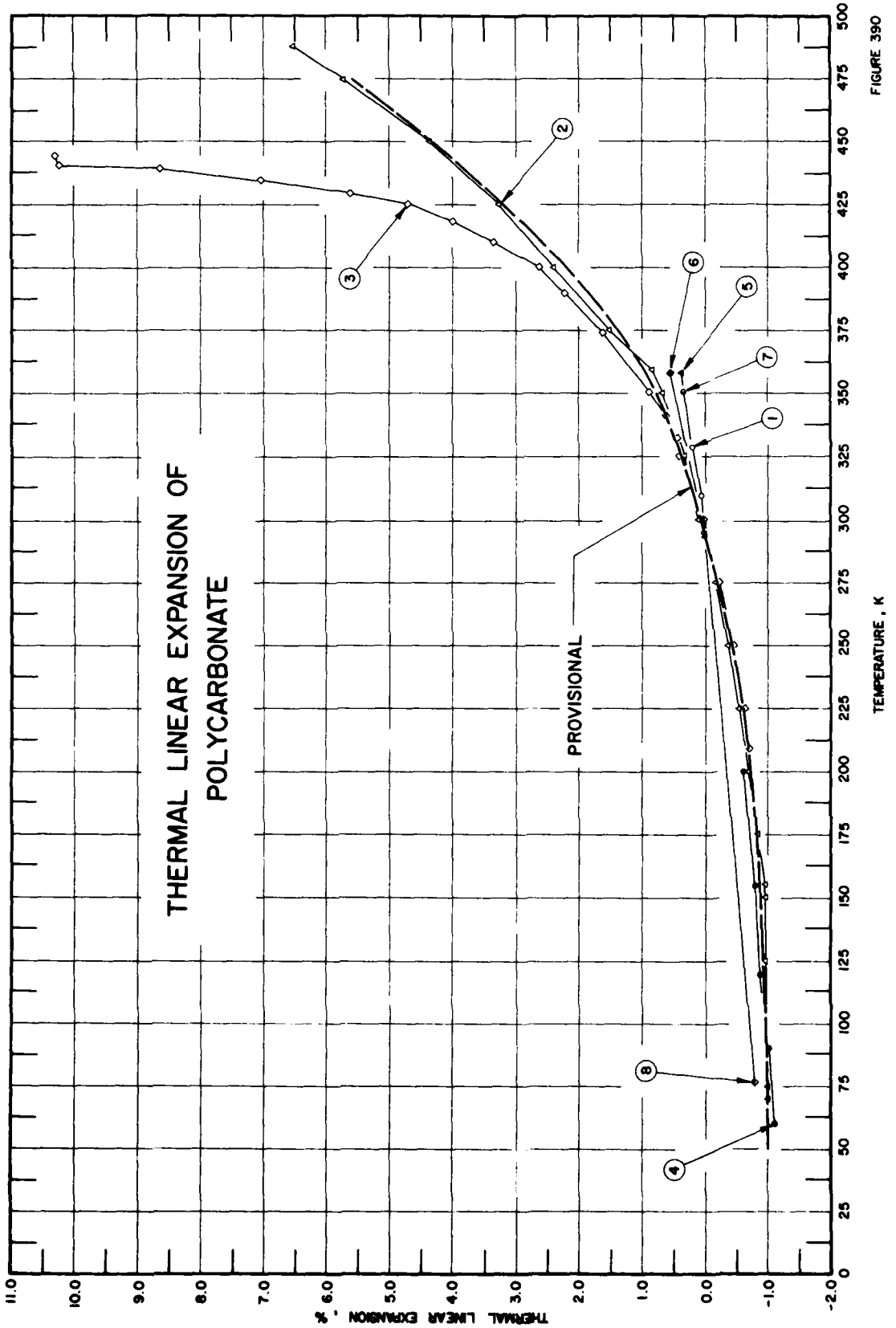

THERMAL LINEAR EXPANSION OF
POLYCARBONATE
PROVISIONAL
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
1
2
3
4
5
6
7
8

FIGURE 390

SPECIFICATION TABLE 390. THERMAL LINEAR EXPANSION OF POLYCARBONATE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	541	Acitelli, M.A., Gumby, W.L., and Naujokas, A.A.	1966	I	295-328		Sample suitably worked to form a tripod placed in furnace of instrument.
2	1048	Schramm, R.E., Clark, A.F., and Reed, R.P.	1973		70-488	Merlon	Specimen of injection grade crystalline; crystallized by immersion in CCl_4 several months; thickness 0.32 cm; flat-tipped quartz probe on DuPont 940 Thermomechanical Analyzer; investigator, Miller, G.W.; Proceedings of the American Chemical Society Symposium on Analytical Calorimetry, San Francisco (Eds. Porter, R.S., Johnson, J.F., Plenum Press, New York, 1968) pg. 71.
3	1048	Schramm, R.E., et al.	1973		209-444	Merlon	Similar to the above specimen; except amorphous specimen.
4	1048	Schramm, R.E., et al.	1973		60-293	Lexan	No details given; investigators, Parmley, R.T., Wong, B., and Skogh, J.; Proceedings of the Conference on Long-Term Cryo-Propellant Storage in Space, sponsored by G.C. Marshall Space Flight Center, 253 (1966).
5	1048	Schramm, R.E., et al.	1973		298, 358	Makrolon	No details given; zero-point correction of 0.03% determined by graphical extrapolation; investigators, Hechelhammer, W., Peilstöcker, G., Kunststoffe 49, 3 (1959).
6	1048	Schramm, R.E., et al.	1973		298, 358	Makrolon	No details given; zero-point correction of 0.043% determined by graphical extrapolation; investigator, Hofmeier, H.; Elektrotech. Z., 11, 412 (1959).
7	1048	Schramm, R.E., et al.	1973		298, 351	Bisphenol-A	Erk VDE 0304/1 test procedure; zero-point correction of 0.03% determined by graphical extrapolation; investigator, Kudra, S., Listy Svazek 57, 1048 (1963).
8	1048	Schramm, R.E., et al.	1973		77, 300		Specimen of length 2.54 cm, diameter 0.95 cm; submerged in liquid N_2, then measured with micrometer, measurement repeated 6-8 times until no further contraction noted; zero-point correction of 0.025% determined by graphical interpolation; investigators, Wisander, D.W. and Johnson, R.L.; Lewis Research Center, Cleveland, Ohio, NASA Tech. Note D-5073 (1969).

DATA TABLE 390. THERMAL LINEAR EXPANSION OF POLYCARBONATE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
295	0.009
309	0.077
328	0.210
CURVE 2	
70	-1.00
75	-1.00
125	-0.96
150	-0.95
155	-0.94
175	-0.83
200	-0.69
225	-0.52
250	-0.36
275	-0.16
293	0.00
300	0.08
325	0.36
350	0.69
359	0.86
375	1.52
400	2.40
425	3.27
450	4.37
475	5.74
488	6.52
CURVE 3	
209	-0.70
225	-0.61
250	-0.43
275	-0.20
293	0.00*
300	0.08*
324	0.41
332	0.42
341	0.61
350	0.88
373	1.61
389	2.21
400	2.62
410	3.34
418	4.00
CURVE 3 (cont.)	
425	4.72
429	5.63
434	7.04
439	8.64
441	10.23
444	10.30
CURVE 4	
60	-1.10
90	-1.00
119	-0.88
154	-0.78
200	-0.60
225	-0.47*
293	0.00*
CURVE 5	
298	0.03
358	0.39
CURVE 6	
298	0.043*
358	0.553
CURVE 7	
298	0.03*
351	0.35
CURVE 8	
77	-0.775
300	0.025

* Not shown in figure.

SPECIFICATION TABLE 391. THERMAL LINEAR EXPANSION OF CELLULOSE ACETATE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	548	Laquer, H. L. and Head, E. L.	1952	L	0-320	Tenite I	Cylindrical specimen 1 in. diameter, 1.5 in. long; obtained from Tennessee Eastman Corp.; molded under 5000 psi at 423 K for 20 min; expansion measured parallel to cylinder axis; zero-point correction of -0.296% determined by graphical interpolation.
2*	548	Laquer, H. L. and Head, E. L.	1952	L	0-320	Tenite II	Similar to the above specimen; zero-point correction of -0.202% determined by graphical interpolation.

DATA TABLE 391. THERMAL LINEAR EXPANSION OF CELLULOSE ACETATE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*	
0	-1.856	0	-2.207
20	-1.836	20	-2.187
40	-1.791	40	-2.147
60	-1.736	60	-2.092
80	-1.676	80	-2.017
100	-1.606	100	-1.922
120	-1.526	120	-1.805
140	-1.431	140	-1.667
160	-1.321	160	-1.507
180	-1.196	180	-1.327
200	-1.051	200	-1.122
220	-0.886	220	-0.897
240	-0.696	240	-0.652
260	-0.471	260	-0.385
273	-0.296	273	-0.202
280	-0.201	280	-0.102
300	0.109	300	0.208
320	0.449	320	0.548

* No figure given.

SPECIFICATION TABLE 392. THERMAL LINEAR EXPANSION OF CELLULOSE PROPIONATE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	540	Hagenbuch, L. M.	1950	L	213-347		*Expansion measured at equilibrium temperature.*

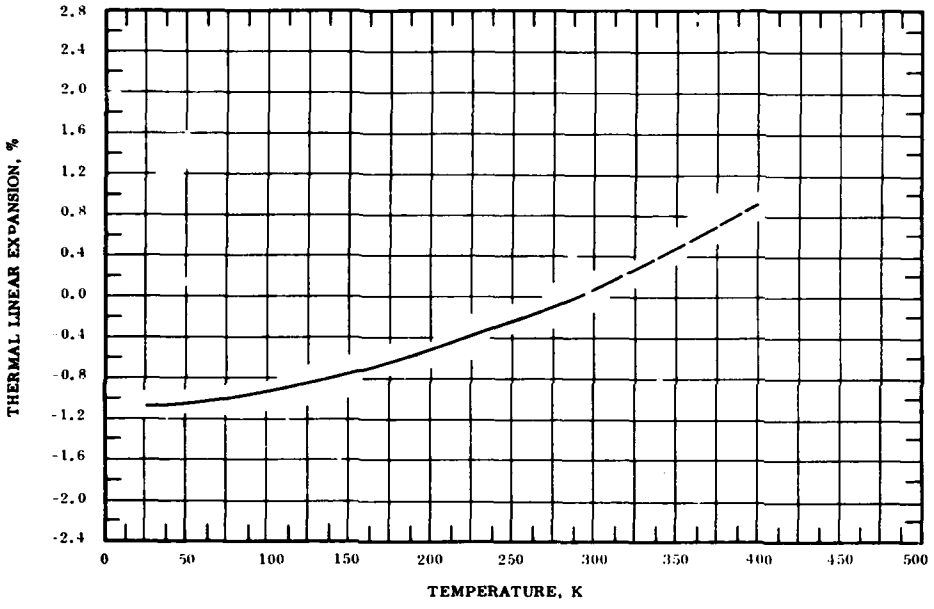
DATA TABLE 392. THERMAL LINEAR EXPANSION OF CELLULOSE PROPIONATE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
213	-0.771
229	-0.611
233	-0.569
283	-0.092
293	0.000
333	0.387
347	0.504

* No figure given.

FIGURE AND TABLE NO. 393R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF POLY(CHLORO TRIFLUOROETHYLENE)



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
25	-1.082	5
50	-1.057	15
75	-1.009	23
100	-0.940	31
125	-0.853	38
150	-0.751	44
175	-0.636	50
200	-0.511	56
225	-0.379	62
250	-0.241	67
275	-0.101	73
293	0.000	76
325	0.265†	83
350	0.459†	87
375	0.683†	92
400	0.916†	95

† Provisional values.

REMARKS

The recommended values are based on the data for Kel-F and Fluorethene samples (Curve 1, 2, 7, and 8) and are considered accurate to within ±5% at temperatures below 293 K and ±10% above 293 K. These values are represented approximately by the following equations:

$$\Delta L/L_0 = -1.081 - 5.870 \times 10^{-4} T + 2.273 \times 10^{-5} T^2 - 2.775 \times 10^{-8} T^3 \quad (25\text{-}293\ K)$$

$$\Delta L/L_0 = 0.149 - 1.126 \times 10^{-2} T + 4.696 \times 10^{-5} T^2 - 3.507 \times 10^{-8} T^3 \quad (293\text{-}400\ K)$$

The tabulated values for the coefficients of thermal expansion are primarily obtained by differentiating the above equations and are considered accurate to about ±10%.

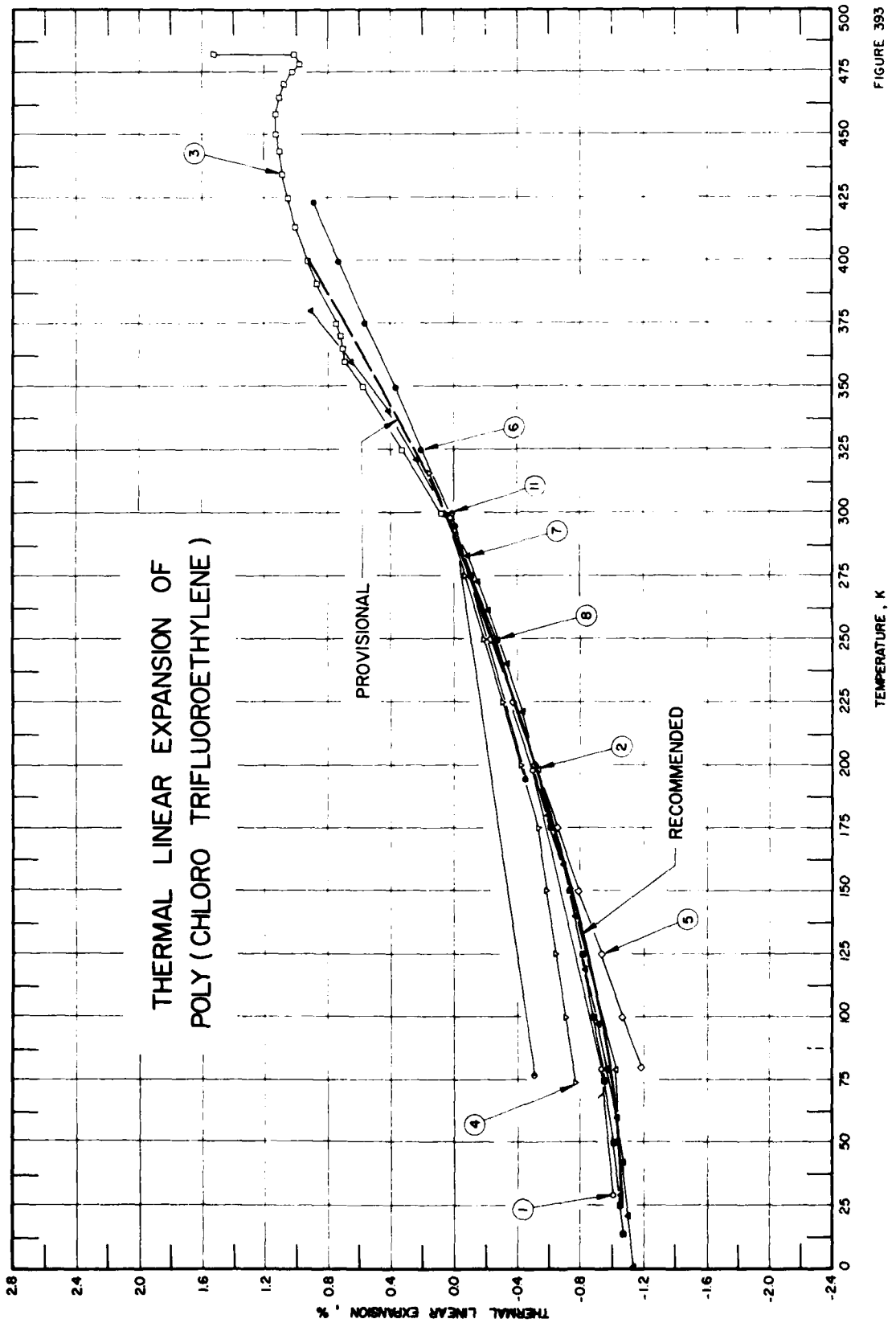

THERMAL LINEAR EXPANSION OF
POLY (CHLORO TRIFLUOROETHYLENE)
PROVISIONAL
RECOMMENDED
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
-1.6
-2.0
-2.4
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
1
2
3
4
5
6
7
8
11

FIGURE 393

SPECIFICATION TABLE 393. THERMAL LINEAR EXPANSION OF POLY(CHLORO TRIFLUOROETHYLENE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1048	Schramm, R.E., Clark, A.F., and Reed, R.P.	1973	L	29-298	Kel-F 300	Specimen of length 10.7 cm; zero-point correction of 0.025%; investigators: Belton, J.H., Godby, L.L., and Taft, B.L., American Society for Testing Materials, Special Technical Publication, 287, 108 (1960).
2	1048	Schramm, R.E., et al.	1973	L	29-298	Kel-F 500	Specimen of length 10.7 cm; zero-point correction of 0.025%; investigators, Belton, J.H., Godby, L.L., and Taft, B.L., American Society for Testing Materials, Special Technical Publication, 287, 108 (1960).
3	1048	Schramm, R.E., et al.	1973		293-482	Daiflon Film	No details given; zero-point correction of 0.031%; investigator: Yano, Y., OYO Butsuri, 27, 274 (1958).
4	1048	Schramm, R.E., et al.	1973		74-316	Lox Grade Kel-F	Thermal linear expansion values calculated from average coefficients of contraction over the temperature ranges 77-173 K and 173-296 K; zero-point correction of 0.027%; investigator: Curry, J.E., NASA Tech. Memorandum X-53183 (1964).
5	1048	Schramm, R.E., et al.	1973	L	80-316	Kel-F Elastomer	Cylinder specimen of length 5.08 cm, diameter 1.27 cm; zero-point correction of 0.032%; investigators: Tipton, F.W., Trepus, G.E., Roper, R.S., Weitzel, D.H., and Robbins, R.F.; Proceedings Joint Army-Navy-Air Force Conference on Elastomer Research and Development, (1960).
6	1048	Schramm, R.E., et al.	1973		194-423		Unplasticized grades 270-300; sp. gr. 2.1; ASTM D696-44 test procedure; calculated from average coefficients of contraction over temperature ranges 193-293 K and 293-423 K; zero-point correction of -0.007%; investigator: Troester, F.W., Corrosion, 16, No. 6, 14 (1960).
7	548	Laquer, H.L. and Head, E.L.	1952	L	0-380	Fluoroethene	Rod specimen of 0.508 cm diameter cut perpendicular to original rod; annealed or slowly cooled; milky appearance; zero-point correction of 0.043%.
8	1049	Bringer, R.P.	1962		13-316		Kel-F 81 Brand Plastic obtained from 3M Co.; zero-point correction of 0.038%.
9*	1050	Hertz, J.	1966		75-295		Kel-F (270/300 NST), as received; thickness 1.27 cm; tested perpendicular to length; zero-point correction of -0.007%.
10*	1050	Hertz. J.	1966		75-295		Kel-F (270/300 NST), as received; tested perpendicular to thickness; specimens prepared by slicing initial specimens into 1.27 cm wide strips which rotated 90° and bonded with epoxy-polymide adhesive; surfaces then ground flat and parallel; zero-point correction of -0.007%.
11	1047	Wisander, D.W. and Johnson, R.L.	1969		77, 300		Specimen of length 2.54 cm, diameter 0.95 cm; submerged in liquid N_2 and measured with micrometer, measurement repeated 6-8 times until no further contraction noted; zero-point correction of 0.014% determined by graphical interpolation.

*Not shown in figure.

DATA TABLE 393. THERMAL LINEAR EXPANSION OF POLY(CHLORO TRIFLUOROETHYLENE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
29	-1.011
79	-0.931
198	-0.494
293	0.000
298	0.025
CURVE 2	
29	-1.057
79	-1.029
198	-0.528
293	0.000
298	0.025
CURVE 3	
293	0.000
298	0.031
300	0.083
325	0.338
350	0.582
360	0.692
365	0.713
370	0.722
375	0.750
391	0.881
400	0.929
413	1.009
425	1.065
434	1.099
443	1.117
450	1.136
458	1.137
465	1.119
470	1.084
475	1.038
478	0.990
482	1.028
482	1.531
CURVE 4	
74	-0.771
100	-0.709
125	-0.645
150	-0.586
CURVE 4 (cont.)	
175	-0.531
200	-0.418
225	-0.300
250	-0.190
275	-0.074
293	0.000
297	0.027
300	0.056
316	0.161
CURVE 5	
80	-1.192
100	-1.068
125	-0.929
150	-0.790
175	-0.651
200	-0.507
225	-0.367
250	-0.231
275	-0.085
293	0.000
297	0.032
300	0.061
316	0.166
CURVE 6	
194	-0.451
200	-0.423
225	-0.310
250	-0.200
275	-0.089
293	0.000
295	-0.007
300	0.036
325	0.210
350	0.378
375	0.566
400	0.735
423	0.893
CURVE 7	
0	-1.138
21	-1.105
CURVE 7 (cont.)	
42	-1.071
60	-1.027
79	-0.964
97	-0.911
119	-0.827
140	-0.764
160	-0.691
180	-0.599
201	-0.516
221	-0.432
240	-0.335
261	-0.209
273	-0.142
283	-0.083
293	0.000
298	0.043
300	0.070
321	0.245
340	0.424
360	0.663
380	0.913
CURVE 8	
13	-1.076
25	-1.056
50	-1.015
75	-0.957
100	-0.887
125	-0.811
150	-0.733
175	-0.622
200	-0.526
225	-0.392
250	-0.264
275	-0.116
293	0.000
297	0.038
300	0.067
316	0.172
CURVE 9*	
75	-0.931
160	-0.694
220	-0.459
CURVE 9 (cont.)	
293	0.000
295	-0.001
CURVE 10*	
75	-1.007
160	-0.729
220	-0.459
293	0.000
295	-0.007
CURVE 11	
77	-0.516
300	0.014

*Not shown in figure.

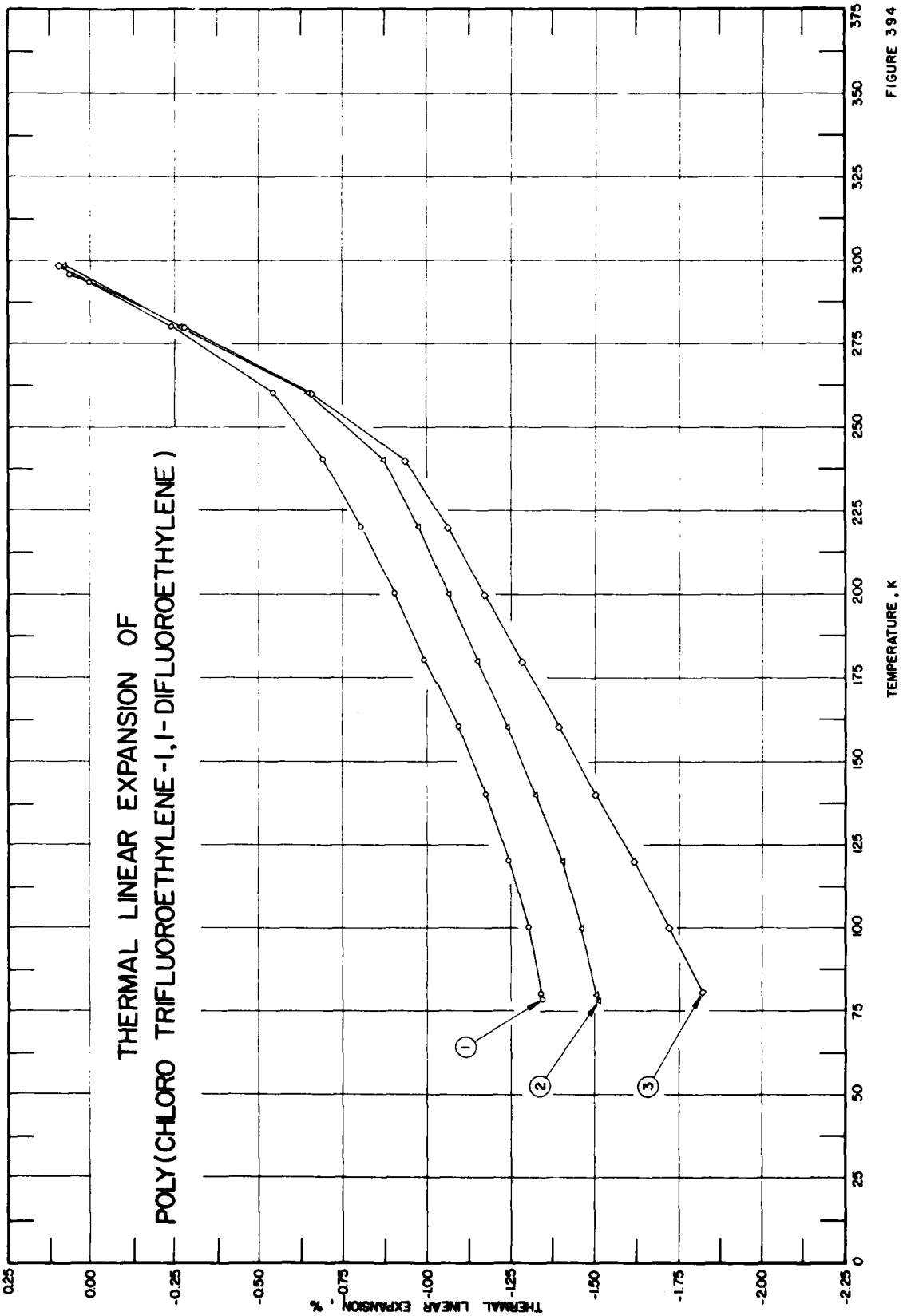

THERMAL LINEAR EXPANSION OF
POLY(CHLORO TRIFLUOROETHYLENE-1,1-DIFLUOROETHYLENE)
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
-1.75
-2.00
-2.25
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
1
2
3

FIGURE 394

SPECIFICATION TABLE 394. THERMAL LINEAR EXPANSION OF POLY(CHLORO TRIFLUOROETHYLENE-1,1-DIFLUOROETHYLENE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	538	Weitzel, D.H., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1963	L	78-296	I-12D	Kel F 5500, from Minnesota Mining and Manufacturing; cured 20 min at 411 K, past cure 16 hr at 422 K; zero-point correction of -0.067%.
2	538	Weitzel, D.H., et al.	1963	L	78-298	I-12E	Kel F 3700, from Minnesota Mining and Manufacturing; cured 30 min at 427 K, past cure 13 hr at 422 K; zero-point correction of -0.079%.
3	538	Weitzel, D.H., et al.	1963	L	81-298	I-25A	Similar to the above specimen except cured 20 min at 411 K; zero-point correction of -0.092%.

DATA TABLE 394. THERMAL LINEAR EXPANSION OF POLY(CHLORO TRIFLUOROETHYLENE-1,1-DIFLUOROETHYLENE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3	
78	-1.347	78	-1.511	81	-1.824
80	-1.341	80	-1.505	100	-1.720
100	-1.308	100	-1.463	120	-1.614
120	-1.249	120	-1.403	140	-1.506
140	-1.175	140	-1.325	160	-1.393
160	-1.090	160	-1.238	180	-1.283
180	-0.997	180	-1.151	200	-1.175
200	-0.903	200	-1.067	220	-1.063
220	-0.805	220	-0.975	240	-0.938
240	-0.693	240	-0.870	260	-0.656
260	-0.549	260	-0.648	280	-0.278
280	-0.243	280	-0.266	293	0.000*
293	0.000	293	0.000*	298	0.092
296	0.067	298	0.079		

* Not shown in figure.

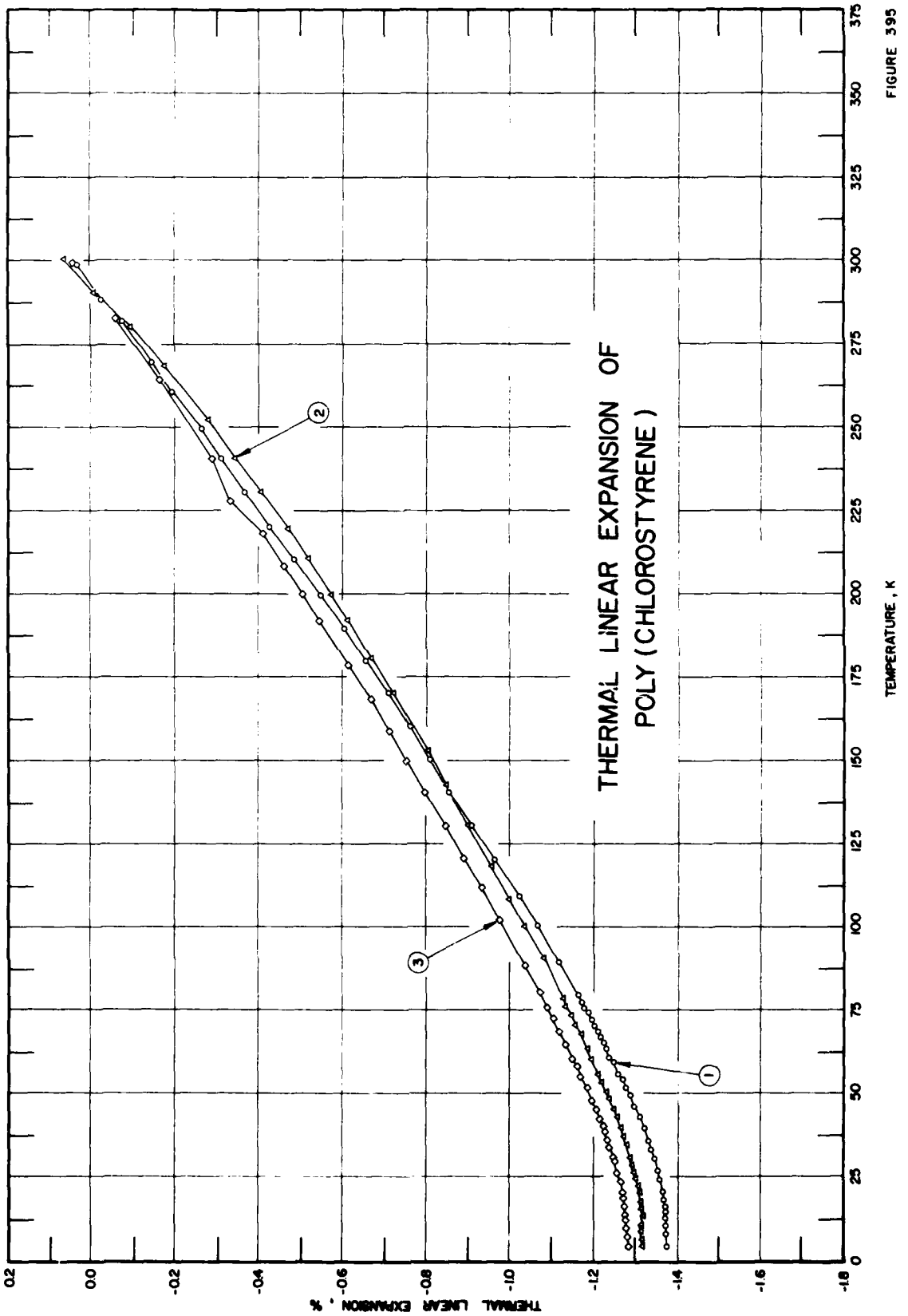

THERMAL LINEAR EXPANSION OF
POLY (CHLOROSTYRENE)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
1
2
3

FIGURE 395

SPECIFICATION TABLE 395. THERMAL LINEAR EXPANSION OF POLY(CHLOROSTYRENE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	549	Saba, R.G.	1967	E	4.2-298		Four specimens of para-chlorostyrene polymerized; three specimens received as polymers; one received from Dow Chemical Co. as monomer and polymerized at 373 K for 4.5 hr; purified by freeze drying and allowing solvent to sublime; three specimens received as polymers: non-homogeneous, streaked, and translucent; fourth specimen clear and homogeneous; density 1.227 ± 0.002 g cm^{-3}; expansion measured using specimen as dielectric in capacitor and observing change in capacitance; data results obtained on all four specimens.
2	549	Saba, R.G.	1967	E	4.2-300		Two specimens of poly (m-chlorostyrene) received as polymers; one received from NBS, one from Dow Chemical Co.; both specimens clear and transparent, density 1.244 ± 0.002 g cm^{-3}; expansion measured as above.
3	549	Saba, R.G.	1967	E	4.2-300		Ortho-chlorostyrene monomer received from Dow Chemical Co.; after purification, polymerized 2.25 hr in bath at 373 K; achieved 36% conversion; purified by dry-freezing and allowing monomer to sublime; clear, transparent, homogeneous specimen, density 1.252 ± 0.001 g cm^{-3}; expansion measured as above.

DATA TABLE 395. THERMAL LINEAR EXPANSION OF POLY(CHLOROSTYRENE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
4.2	-1.376
7.6	-1.374
11.2	-1.372
12.7	-1.371
14.6	-1.370
16.5	-1.368
18.7	-1.366
21.2	-1.363
23.7	-1.358
27.2	-1.352
30.2	-1.345
32.7	-1.339
35.7	-1.331
39.1	-1.321
42.8	-1.310
46.6	-1.298
49.3	-1.288
51.7	-1.279
54.2	-1.269
56.6	-1.259
59.5	-1.248
61.8	-1.239
63.6	-1.231
65.2	-1.225
67.0	-1.217
68.8	-1.210
70.5	-1.202
72.3	-1.195
74.0	-1.187
75.6	-1.179
77.3	-1.172
79.4	-1.163
89.1	-1.119
100.1	-1.067
109.0	-1.023
120.8	-0.964
131.6	-0.909
141.9	-0.856
150.9	-0.809
160.1	-0.761
170.0	-0.708
180.0	-0.655
189.5	-0.602
199.4	-0.547
210.7	-0.485
220.5	-0.429

T	$\Delta L/L_0$
CURVE 1 (cont.)	
231.8	-0.366
241.8	-0.308
249.8	-0.262
261.8	-0.191
269.6	-0.144
282.2	-0.073
288.9	-0.025
298.2	0.032
CURVE 2	
4.2	-1.319
6.5	-1.318
8.6	-1.316
10.7	-1.315
13.1	-1.319
15.5	-1.315
17.6	-1.313
20.1	-1.309
22.1	-1.305
24.7	-1.300
26.5	-1.298
28.8	-1.295
31.2	-1.287
34.4	-1.280
37.0	-1.273
39.7	-1.265
42.7	-1.256
45.4	-1.248
48.6	-1.238
50.8	-1.231
53.9	-1.220
56.8	-1.210
60.2	-1.198
63.9	-1.184
67.6	-1.170
70.5	-1.159
73.7	-1.146
76.9	-1.133
78.5	-1.130
90.4	-1.080
100.3	-1.037
108.9	-0.999
118.0	-0.959
131.6	-0.900
142.7	-0.849

T	$\Delta L/L_0$
CURVE 2 (cont.)	
152.9	-0.803
170.4	-0.720
181.1	-0.668
192.2	-0.613
199.4	-0.576
211.0	-0.520
219.9	-0.470
231.1	-0.407
241.6	-0.346
252.4	-0.280
268.5	-0.174
280.5	-0.091
291.5	-0.010
300.8	0.063
CURVE 3	
4.2	-1.281
7.0	-1.280
9.7	-1.278
12.0	-1.277
13.8	-1.275
16.3	-1.273
18.2	-1.270
20.3	-1.267
23.3	-1.262
26.2	-1.256
29.2	-1.249
31.5	-1.244
33.9	-1.238
36.1	-1.232
38.1	-1.226
40.0	-1.221
42.4	-1.213
45.1	-1.205
47.9	-1.196
52.0	-1.182
55.5	-1.168
57.8	-1.160
61.0	-1.148
64.7	-1.134
68.7	-1.118
72.5	-1.103
76.3	-1.087
80.3	-1.071
88.6	-1.037

T	$\Delta L/L_0$
CURVE 3 (cont.)	
102.4	-0.975
112.0	-0.932
121.5	-0.888
131.0	-0.845
140.8	-0.798
150.0	-0.753
158.9	-0.710
168.0	-0.666
178.5	-0.613
192.1	-0.545
200.5	-0.501
208.1	-0.461
218.0	-0.411
232.7	-0.334
241.3	-0.288
264.8	-0.161
282.6	-0.060
290.3	-0.016*
299.6	0.040

* Not shown in figure.

SPECIFICATION TABLE 396. THERMAL LINEAR EXPANSION OF POLY(N-DECYL METHACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	543	Haldon, R.A. and Simha, R.	1968	V	99-226	PnDMA	Specimen 0.25 in. diameter, 1.0 in. long; obtained from Dr. D.L. Glusker of Dohm and Haas Co.; ends of cylinder filed flat, stored in vacuum.
2*	544	Haldon, R.A. and Simha, R.	1968	L	25-114	PnDMA	This curve is here reported using the first given temperature (25 K) as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 396. THERMAL LINEAR EXPANSION OF POLY(N-DECYL METHACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 2 (cont.)*,†,‡		CURVE 2 (cont.)*,†,‡	
99	-1.807	148	-1.499	189	-1.216	223	-0.887	55	0.065	91	0.205
104	-1.779	153	-1.467	192	-1.189	226	-0.849	59	0.078	93	0.218
109	-1.751	156	-1.448	194	-1.171			62	0.092	96	0.229
114	-1.721	160	-1.423	199	-1.125	CURVE 2*,†,‡		66	0.105	98	0.241
119	-1.689	164	-1.397	202	-1.097			70	0.119	101	0.253
123	-1.663	168	-1.370	205	-1.069	25	0.000	72	0.129	104	0.266
128	-1.631	171	-1.350	208	-1.042	33	0.008	76	0.142	106	0.278
133	-1.598	175	-1.322	211	-1.015	38	0.017	79	0.154	109	0.291
137	-1.571	179	-1.294	214	-0.987	43	0.028	82	0.166	111	0.306
141	-1.545	182	-1.272	217	-0.956	48	0.042	85	0.177	114	0.316
144	-1.525	185	-1.249	221	-0.911	51	0.052	88	0.192		

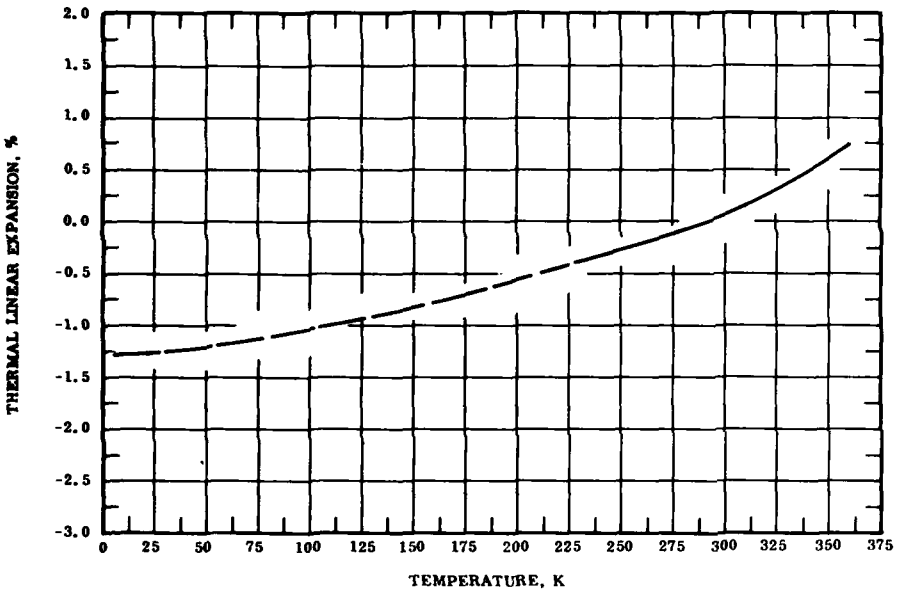
DATA TABLE 396. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(N-DECYL METHACRYLATE)

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α	T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 2 (cont.)*,‡		CURVE 2 (cont.)*,‡	
99	54.0	148	64.1	189	85.3	223	124.6	55	36.0	91	47.2
104	56.2	153	64.1	192	88.8	226	128.7	59	36.5	93	47.2
109	58.0	156	62.5	194	92.8			62	37.4	96	47.2
114	61.9	160	63.6	199	93.4	CURVE 2*,‡		66	36.7	98	46.6
119	63.8	164	65.5	202	93.4			70	36.7	101	47.2
123	65.1	168	67.5	205	90.4	25	7.7	72	37.0	104	47.1
128	65.5	171	68.5	208	89.3	33	14.4	76	37.0	106	49.0
133	66.4	175	70.1	211	91.1	38	19.5	79	39.6	109	50.7
137	66.4	179	71.4	214	99.5	43	24.1	82	41.1	111	50.6
141	66.4	182	75.0	217	107.3	48	31.2	85	43.8	114	49.6
144	65.3	185	80.3	221	116.9	51	34.3	88	45.9		

* No figure given.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 397R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF POLYESTER



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
5	-1.273†	17
10	-1.264†	18
20	-1.245†	20
40	-1.200†	24
60	-1.147†	28
80	-1.087†	32
100	-1.018†	36
125	-0.922†	41
150	-0.815†	45
175	-0.696†	49
200	-0.567†	54
225	-0.428†	58
250	-0.279	63
275	-0.120	73
293	0.000	84
320	0.253	107
340	0.486	127
360	0.762	149

† Provisional values.

REMARKS

The recommended values are based on the data for the cured samples without reinforcement and are considered accurate to within ± 5% at temperatures above 225 K and ± 10% below 225 K. These values are represented approximately by the following equations:

$$\Delta L/L_0 = -1.281 + 1.615 \times 10^{-2}\, T + 1.054 \times 10^{-5}\, T^2 - 3.866 \times 10^{-9}\, T^3 \qquad (5\text{-}293\ K)$$

$$\Delta L/L_0 = -0.506 - 7.776 \times 10^{-3}\, T + 7.817 \times 10^{-6}\, T^2 + 4.377 \times 10^{-8}\, T^3 \qquad (293\text{-}360\ K)$$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equations and are considered accurate to about ± 10%.

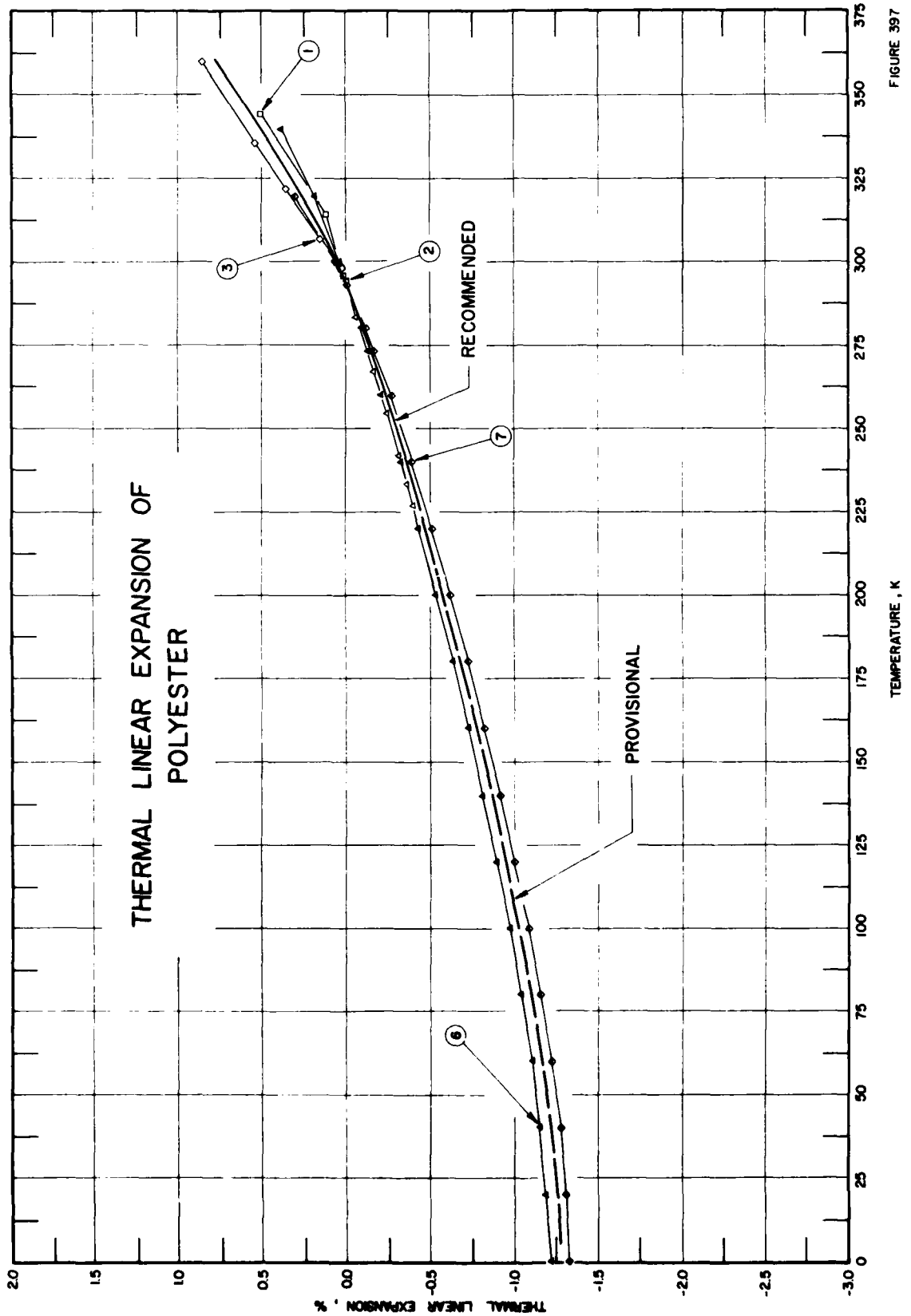

THERMAL LINEAR EXPANSION OF POLYESTER
RECOMMENDED
PROVISIONAL
1
2
3
6
7
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375

FIGURE 397

SPECIFICATION TABLE 397. THERMAL LINEAR EXPANSION OF POLYESTER

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	541	Acitelli, M.A., Gumby, W.L., and Nanjokas, A.A.	1966	I	296-344	Paraplex p-444A	Sample suitably worked to form a tripod placed in furnace of instrument.
2	539	Tramposch, H. and Gerard, G.	1957	S	227-294	Paraplex p-43	Photo-thermoelastic plastic sample; zero-point correction of -0.124% determined by graphical interpolation.
3	987	Menges, G. and Brintrup, D.H.	1974	L	293-360		Specimen of not reinforced polyester standard resin; 50 x 50 x plate thickness (mm).
4*	548	Laquer, H.L. and Head, E.L.	1952	L	0-320		Dynakon rod F, 0.146 in. diameter; glass fiber reinforced, molded polyester rod of very high tensile and flexural strength, made by Dynakon Corp., Cleveland, Ohio.
5*	548	Laquer, H.L. and Head, E.L.	1952	L	0-340		Dynakon sheet A3A, 1/8 in. thick, glass fiber reinforced molded polyester sheet, made by Dynakon Corp.
6	548	Laquer, H.L. and Head, E.L.	1952	L	0-340		Laminac 4129, unsaturated polyester made by American Cyanamide Co., catalyzed with 0.3 wt% of tert-butyl hydroparoxide and cast into 3/4 in. diameter test tube; polymerization initiated during 48 hr preliminary cure at room temperature and completed with 1 hr at 100 C; sample had milky appearance.
7	548	Laquer, H.L. and Head, E.L.	1952	L	0-320		Selectron 5026, unsaturated polyester made by Columbia Resins Division, Pittsburgh Plate Glass Co., transparent sample prepared with exactly the same catalyst and temperature cycle as the above sample.

* Not shown in figure.

DATA TABLE 397. THERMAL LINEAR EXPANSION OF POLYESTER

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
296	0.018
314	0.124
344	0.510
CURVE 2	
227	-0.400
233	-0.369
242	-0.311
254	-0.241
267	-0.153
283	-0.054
294	0.007
CURVE 3	
293	0.000
298	0.050
307	0.152
322	0.351
336	0.540
360	0.854
CURVE 4*	
0	-0.282
20	-0.279
40	-0.271
60	-0.261
80	-0.248
100	-0.233
120	-0.215
140	-0.194
160	-0.172
180	-0.148
200	-0.123
220	-0.098
240	-0.072
260	-0.045
273.2	-0.027
280	-0.018
300	0.009
320	0.036

T	$\Delta L/L_0$
CURVE 5*	
0	-0.428
20	-0.422
40	-0.407
60	-0.388
80	-0.366
100	-0.342
120	-0.315
140	-0.286
160	-0.255
180	-0.222
200	-0.187
220	-0.150
240	-0.111
260	-0.070
273.2	-0.042*
280	-0.028
300	0.015*
320	0.060
340	0.106
CURVE 6	
0	-1.205
20	-1.189
40	-1.155
60	-1.105
80	-1.043
100	-0.972
120	-0.894
140	-0.812
160	-0.725
180	-0.633
200	-0.536
220	-0.433
240	-0.324
260	-0.208
273.2	-0.127
280	-0.085
300	0.046
320	0.199
340	0.384

T	$\Delta L/L_0$
CURVE 7	
0	-1.325
20	-1.311
40	-1.276
60	-1.223
80	-1.156
100	-1.081
120	-1.000
140	-0.913
160	-0.821
180	-0.724
200	-0.621
220	-0.511
240	-0.392
260	-0.262
273.2	-0.170
280	-0.118
300	0.063
320	0.309

* Not shown in figure.

SPECIFICATION TABLE 398. THERMAL LINEAR EXPANSION OF POLY(ETHYL ACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	538	Weltzel, D.H., Robbins, R.F., Ludtke, P.R., and Obori, Y.	1963	L	76-296	Hycar 4021 rubber	Specimen obtained from B.F. Goodrich; cured 45 min at 427 K; zero-point correction of -0.060%.

DATA TABLE 398. THERMAL LINEAR EXPANSION OF POLY(ETHYL ACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
76	-1.983
80	-1.958
100	-1.833
120	-1.705
140	-1.582
160	-1.462
180	-1.338
200	-1.218
220	-1.093
240	-0.963
260	-0.720
280	-0.292
293	0.000
296	0.060

* No figure given.

SPECIFICATION TABLE 399. THERMAL LINEAR EXPANSION OF POLY(ETHYL METHACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	*Method* Used	*Temp.* Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	543	Haldon, R.A. and Simha, R.	1968	V	99–362	PEMA	Specimen 0.25 in. diameter, 1.0 in. long; obtained as transparent sheet from Dr. D.L. Gluster of Rohm and Hass Co.; molded at 438 K and 500 psi; annealed at about 293 K prior to measurement.
2*	544	Haldon, R.A. and Simha, R.	1968	L	25–110	PEMA	Glass transition temperature at 110 K; this curve is here reported using the first given temperature (25 K) as reference temperature at which $\Delta L/L_0 = 0$.

* No figure given.

DATA TABLE 399. THERMAL LINEAR EXPANSION OF POLY(ETHYL METHACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 2*,†,‡	
99	-1.43	260	-0.32	25	0.000
104	-1.42	263	-0.29	32	0.006
108	-1.42	266	-0.27	37	0.014
114	-1.42	268	-0.24	41	0.022
119	-1.32	270	-0.22	47	0.034
123	-1.30	273	-0.19	50	0.044
128	-1.27	275	-0.17	54	0.056
132	-1.24	278	-0.14	58	0.068
136	-1.22	281	-0.12	62	0.082
140	-1.19	283	-0.09	65	0.093
144	-1.17	286	-0.07	68	0.105
148	-1.14	288	-0.05	72	0.117
152	-1.12	291	-0.02	74	0.127
156	-1.09	293	0.00	78	0.139
160	-1.07	296	0.03	80	0.149
163	-1.05	298	0.05	83	0.160
167	-1.02	300	0.08	86	0.172
171	-0.99	303	0.10	89	0.183
174	-0.97	306	0.14	92	0.195
177	-0.95	308	0.16	95	0.206
182	-0.92	310	0.19	97	0.218
185	-0.90	312	0.21	100	0.231
188	-0.88	315	0.24	102	0.241
192	-0.85	318	0.28	106	0.255
195	-0.83	320	0.30	108	0.267
198	-0.80	322	0.32	110	0.279
201	-0.78	325	0.36		
205	-0.75	326	0.38		
208	-0.73	330	0.41		
211	-0.71	331	0.44		
214	-0.69	333	0.46		
217	-0.66	335	0.49		
220	-0.64	338	0.53		
223	-0.62	340	0.57		
226	-0.59	342	0.60		
228	-0.57	344	0.65		
232	-0.54	346	0.69		
236	-0.52	349	0.74		
238	-0.50	352	0.79		
240	-0.48	355	0.86		
243	-0.45	358	0.90		
246	-0.43	360	0.93		
250	-0.41	362	0.98		
252	-0.39				
255	-0.36				
257	-0.34				

* No figure given.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 399. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(ETHYL METHACRYLATE)

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1*,‡	
99	45.7
104	49.2
108	52.1
114	56.1
119	58.1
123	59.7
128	60.4
132	61.3
136	60.6
140	59.4
144	60.6
148	60.1
152	62.2
156	63.8
160	66.9
163	69.0
167	69.8
171	70.7
174	71.1
177	70.2
182	70.2
185	70.2
188	70.2
192	70.7
195	71.6
198	71.6
201	72.3
205	73.3
208	74.8
211	75.3
214	76.2
217	77.1
220	77.1
223	77.1
226	77.1
228	77.5
232	78.9
236	78.9
238	78.9
240	79.9
243	79.6
246	80.3
250	80.3
252	82.1
255	83.7

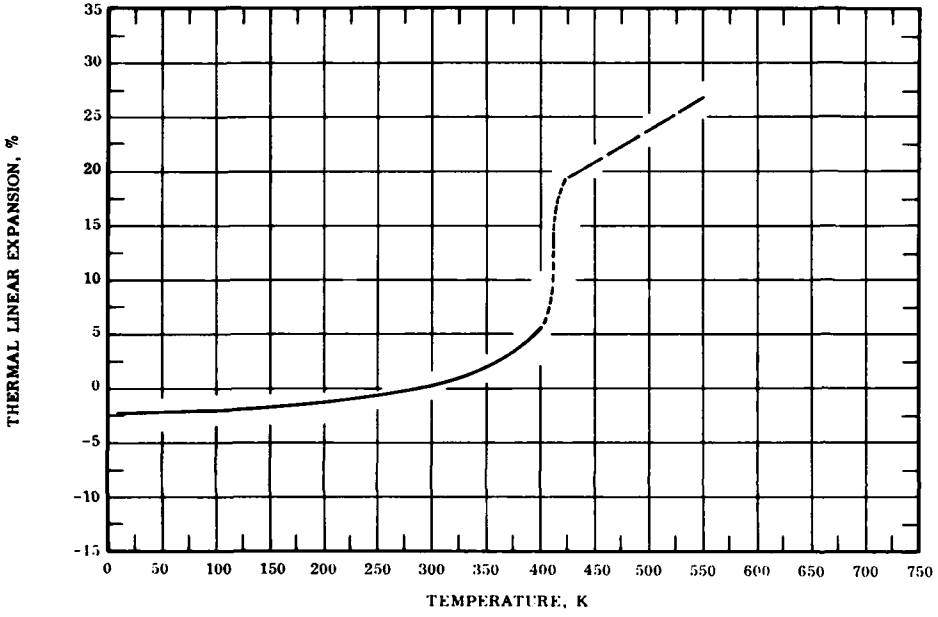
T	α
CURVE 1 (cont.)*,‡	
257	88.3
260	90.4
263	94.3
266	98.2
268	96.6
270	96.2
273	96.2
275	96.2
278	97.6
281	95.6
283	95.6
286	96.6
288	98.3
291	99.3
293	101.4
296	105.1
298	106.4
300	108.5
303	109.9
306	111.5
308	112.8
310	114.2
312	114.9
315	114.9
318	114.9
320	116.0
322	116.0
325	114.9
326	116.5
330	120.9
331	127.0
333	137.5
335	152.6
338	167.6
340	184.3
342	192.5
344	198.0
346	195.0
349	190.8
352	181.8
355	177.0
358	179.1
360	186.2
362	193.0

T	α
CURVE 2*,‡	
25	6.5
32	11.4
37	17.2
41	21.1
47	24.9
50	30.3
54	32.7
58	34.0
62	35.2
65	36.8
68	35.7
72	35.7
74	35.7
78	36.2
80	37.1
83	38.6
86	38.6
89	40.9
92	41.5
95	43.2
97	43.9
100	44.6
102	45.6
106	47.0
108	47.7
110	49.4

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 400R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF POLYETHYLENE



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
10	-2.44	12
25	-2.41	23
50	-2.34	33
75	-2.25	45
100	-2.12	56
150	-1.76	82
200	-1.30	110
250	-0.67	141
293	0.00	169
325	0.75	330
350	1.60	490
375	3.10	690
400†	5.60	940
425†	19.4‡	
450	21.0‡	
500	24.1‡	
550	27.5‡	

† Glass transition temperature.
‡ Provisional values.

REMARKS

The recommended values are based on the data for high density 0.965 g cm^{-3} homogeneous samples (curves 1, 4, 7, and 21). The variation of the glass transition temperature is due to the expansion measurement at different test pressure (curves 5, 6, 8 and 9). These values are considered accurate to within ± 5% at temperatures below 400 K and ± 10% above 400 K and are represented approximately by the following equation:

$$\Delta L/L_0 = -2.45 + 1.30 \times 10^{-3}\ T + 1.91 \times 10^{-5}\ T^2 + 1.72 \times 10^{-8}\ T^3 \qquad (10\text{-}293\ K)$$

The tabulated values for the coefficient of thermal expansion are based on the selected experimental data and are considered accurate to about ± 7%.

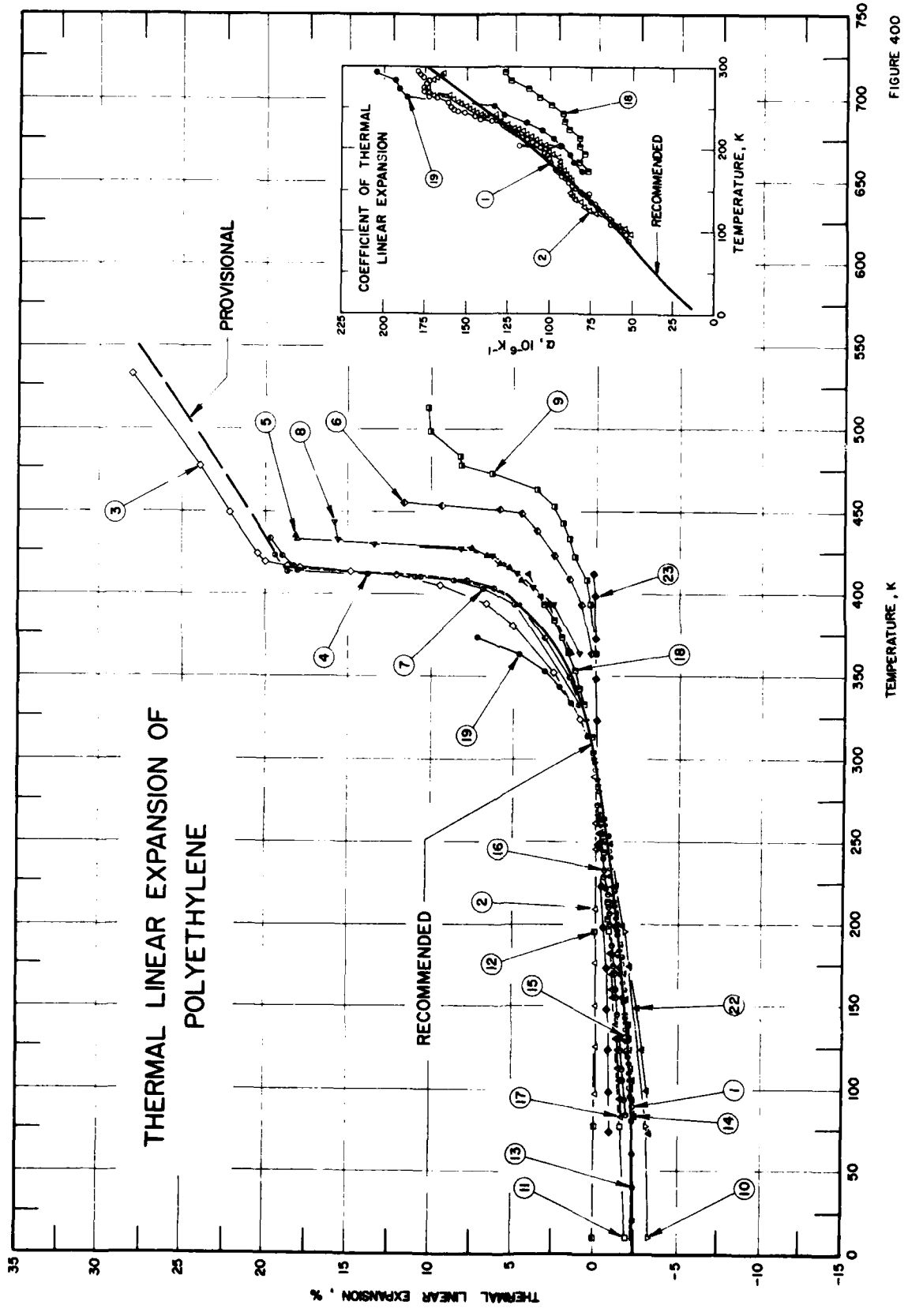

THERMAL LINEAR EXPANSION OF POLYETHYLENE
PROVISIONAL
RECOMMENDED
COEFFICIENT OF THERMAL LINEAR EXPANSION
α, 10⁶ K⁻¹
TEMPERATURE, K
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K

FIGURE 400

SPECIFICATION TABLE 400. THERMAL LINEAR EXPANSION OF POLYETHYLENE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	550	Zakim, J. L., Simha, R., and Hershey, H.C.	1966	V	89-293	Sample I	Specimen obtained from Union Carbide Corp.; raw material machined without heating or annealing; reported error ±3.0%.
2	550	Zakim, J. L. et al.	1966	V	97-293	Sample M	Similar to the above specimen but prepared by casting.
3	551	Waldman, N.	1967	L	293-533	Marlex 5095	Cylindrical specimen, 2.0146 in. long, 0.2553 in. diameter; density 0.9514 g cm^{-3} at 298 K; ten pounds polymer fed to extruder at 491.49 K, barrel 519.27 K, nozzle 505.38 K over 1 1/2 hr period to purge extruder of material to ensure a homogeneous sample; expansion measured at zero psig test pressure.
4	551	Waldman, N.	1967	L	298-433	Marlex 6001	Similar to the above specimen except 2.0714 in. long; density 0.965 g cm^{-3} at 298 K.
5	551	Waldman, N.	1967	L	298-435	Marlex 6001	Similar to the above specimen except 2.0394 in. long; density 0.965 g cm^{-3} at 298 K; expansion measured at 3523 psig test pressure.
6	551	Waldman, N.	1967	L	298-455	Marlex 6001	Similar to the above specimen; expansion measured at 8802 psig test pressure.
7	551	Waldman, N.	1967	L	298-423	Marlex 6002	Similar to the above specimen except 2.1431 in. long; density 0.965 g cm^{-3} at 298 K; expansion measured at zero psig test pressure.
8	551	Waldman, N.	1967	L	298-443	Marlex 6002	Similar to the above specimen except 2.1256 in. long; expansion measured at 3502 psig test pressure.
9	551	Waldman, N.	1967	L	298-513	Marlex 6002	Similar to the above specimen except expansion measured at 8802 psig test pressure.
10	552	Shen, M., Hansen, W.W., and Romo, P.C.	1969	X	10-297	Marlex 6009	Sample supplied by Phillips Petroleum Co. in form of 1-mil sheets; density 0.960 g cm^{-3}; crystallinity 93%; contained up to 0.02 Ionol antioxidant; single crystals grown by dissolving in boiling xylene under nitrogen blanket, then cooled to room temperature, portions of crystal-rich layer drawn from the solution and deposited on sodium chloride sheet; after xylene evaporated under nitrogen, a layer of polyethylene single crystals together with small amount of finely ground high-purity silicon metal as internal standard; adhered to the sample holder; unit cell parameter expansion measured along a-axis; 7.42 Å reported at 297 K; 7.41 Å at 293 K determined by graphical interpolation.
11	552	Shen, M., et al.	1969	X	10-297	Marlex 6009	The above specimen; unit cell parameter; expansion measured along b-axis; 4.96 Å reported at 297 K; 4.958 Å at 293 K determined by graphical interpolation.
12	552	Shen, M., et al.	1969	X	10-297	Marlex 6009	The above specimen; unit cell parameter; expansion measured along c-axis; 2.534 Å reported from 10 to 297 K.
13	548	Laquer, H. L. and Head, E. L.	1952	L	0-300	Polythene PM-1, vinyl polymer	Specimen made by E. I. DuPont de Nemours and Co.; molded under 2000 psi pressure at 150 C for 10 min into cylinders 1.5 in. long and 1 in. diameter; expansion measured parallel to cylinder axis; zero-point correction of -0.360% determined by graphical interpolation.
14	553	Mandelkern, L. and Stehling, F.C.	1969		83-251		Linear polyethylene; low density; 55% crystalline.
15	553	Mandelkern, L. and Stehling, F.C.	1969		83-261		Linear polyethylene; low density; 68% crystalline.
16	553	Mandelkern, L. and Stehling, F.C.	1969		83-273		Linear polyethylene; low density; 70% crystalline.
17	553	Mandelkern, L. and Stehling, F.C.	1969		83-273		Linear polyethylene; low density; 84% crystalline.
18	171	Asay, J.R.	1968		173-393		High density specimen; density 0.967 g cm^{-3}; m.p. 407.7 K.
19	171	Asay, J.R.	1968		173-373		Low density specimen; density 0.922 g cm^{-3}; m.p. 385 K.

SPECIFICATION TABLE 400. THERMAL LINEAR EXPANSION OF POLYETHYLENE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
20	554	Urzendowski, R. and Guenther, A.H.	1969	L	173-373		Specimen of low density 0.922 g cm^{-3}; reported error ±2.5%.
21*	554	Urzendowski, R. and Guenther, A.H.	1969	L	173-393		Specimen of high density 0.967 g cm^{-3}; reported error ±2.5%.
22	555	Swan, P.R.	1962	X	73-412	Marlex 50	Linear specimen of orthorhombic unit cell; modified Norelco 114.6 cm powder camera was used from -70 C to room temperature; high temperature x-ray camera used from 5 C to 130 C; expansion measured along a-axis; unit cell reported at 293 K in 7.398 Å.
23	555	Swan, P.R.	1962	X	73-412	Marlex 50	The above specimen; expansion measured along b-axis; unit all reported at 293 K is 4.945 Å.

* Not shown in figure.

DATA TABLE 400. THERMAL LINEAR EXPANSION OF POLYETHYLENE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
89	-2.259
95	-2.228
100	-2.200
105	-2.170
109	-2.143
115	-2.110
119	-2.078
123	-2.053
128	-2.018
132	-1.993
136	-1.962
141	-1.921
145	-1.892
146	-1.886*
149	-1.862*
152	-1.835
156	-1.803*
160	-1.770*
164	-1.730
167	-1.704*
171	-1.669*
175	-1.626
178	-1.601*
182	-1.560*
184	-1.540
188	-1.500*
193	-1.453*
195	-1.428
198	-1.398*
201	-1.366*
203	-1.346
204	-1.331*
208	-1.289*
211	-1.256
214	-1.223*
217	-1.186
220	-1.154
223	-1.111*
226	-1.074*
229	-1.039*
234	-0.965
237	-0.924*
240	-0.893*
244	-0.834
246	-0.803*
CURVE 1 (cont.)‡	
248	-0.761*
251	-0.716
254	-0.671*
257	-0.617*
259	-0.590
262	-0.534*
264	-0.512*
266	-0.468
267	-0.449*
270	-0.398*
272	-0.365
275	-0.314*
278	-0.258*
280	-0.226
283	-0.179*
285	-0.129*
288	-0.089
290	-0.052*
293	0.000
CURVE 2‡	
97	-0.022
103	-0.021*
107	-0.021*
113	-0.021*
117	-0.020*
121	-0.020*
125	-0.020
130	-0.019*
135	-0.019*
139	-0.019*
143	-0.018*
147	-0.018*
150	-0.018
154	-0.017*
158	-0.017*
162	-0.017*
166	-0.016*
169	-0.016*
173	-0.016*
176	-0.015
180	-0.015*
183	-0.015*
186	-0.015*
CURVE 2 (cont.)‡	
190	-0.014*
193	-0.014*
196	-0.014*
200	-0.013*
204	-0.013*
206	-0.013*
209	-0.012
212	-0.012*
215	-0.012*
218	-0.011*
221	-0.011*
224	-0.011*
227	-0.010*
230	-0.010*
233	-0.009*
236	-0.009*
239	-0.009*
241	-0.008*
241	-0.008
245	-0.008
247	-0.008*
250	-0.007*
253	-0.007*
255	-0.006*
258	-0.006*
261	-0.005
265	-0.005*
265	-0.005*
269	-0.004*
272	-0.004*
284	-0.001*
287	-0.001*
289	-0.001
293	0.000*
CURVE 3	
293.2	0.0000*
324.9	0.9927
352.6	2.6109
380.4	5.0134
394.3	6.6712
405.4	9.4410
411.0	12.1314
413.7	14.8515
415.4	17.9638
416.5	18.6687
419.3	20.0833
424.9	20.4804
449.9	22.1929
477.6	23.9054
533.2	28.0005
CURVE 4	
298	0.1139
323	0.6835
348	1.6925
373	3.1891
393	4.6760
403	6.2063
408	7.8477
410	10.5464
412	13.8244
414	18.0582
416	18.2079
423	18.9031
433	19.6127
CURVE 5	
298	0.1130*
363	1.5821
393	2.8891
408	4.5106
416	5.3852
418	5.7979
423	6.6135
428	7.5569
433	18.0326
435	18.1112
CURVE 6	
298	0.001*
363	0.362
393	0.891
408	1.677
423	2.561
438	3.584
CURVE 6 (cont.)	
448	4.524
451	5.972
453	9.422
455	11.622
CURVE 7	
298	0.003*
333	1.029
373	3.087*
393	4.949
403	6.848
408	8.621
410	10.917
412	13.824*
414	18.682
416	18.761*
423	19.363
CURVE 8	
298	0.002*
363	1.087
393	2.643
403	3.846
408	4.595*
412	4.784
416	5.374*
423	6.260
428	8.232
430	13.485
433	15.551
443	15.815
CURVE 9	
298	0.0003*
363	0.157
393	0.404
408	0.690
423	1.356
433	1.680
443	2.046
453	2.683
463	3.559
CURVE 9 (cont.)	
473	6.385
478	8.212
483	8.226
498	10.167
513	10.167
CURVE 10	
10	-3.374
77	-3.104
195	-1.889
297	0.135*
CURVE 11	
10	-1.977
77	-1.574
195	-0.969
297	0.040*
CURVE 12	
10	0.000
77	0.000
195	0.000
297	0.000*
CURVE 13	
0	-2.450
20	-2.440
40	-2.405
60	-2.350
80	-2.280
100	-2.195*
120	-2.090*
140	-1.965
160	-1.815
180	-1.640
200	-1.440
220	-1.200
240	-0.920
260	-0.595*
273.2	-0.360*
280	-0.240*
300	0.130

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 400. THERMAL LINEAR EXPANSION OF POLYETHYLENE (continued)

T	$\Delta L/L_0$
CURVE 14	
83	-2.444
93	-2.383
105	-2.307
112	-2.256
123	-2.188
130	-2.136
139	-2.062
145	-2.005*
154	-1.920
160	-1.851*
169	-1.764
174	-1.694*
181	-1.608*
187	-1.544
194	-1.448*
199	-1.380*
206	-1.291
211	-1.230*
218	-1.136
222	-1.070
229	-0.970
233	-0.924*
240	-0.815*
244	-0.754
251	-0.659*
CURVE 15	
83	-2.212*
93	-2.163*
105	-2.108*
112	-2.060*
123	-1.998
130	-1.944
139	-1.878*
145	-1.828*
155	-1.746
160	-1.697*
169	-1.612
173	-1.560
181	-1.473
187	-1.423*
194	-1.341*
199	-1.280
206	-1.200*
211	-1.142*
218	-1.060*
222	-1.003*
229	-0.921*
233	-0.860*
240	-0.774*
244	-0.721*
250	-0.639
255	-0.583
261	-0.491
CURVE 16	
83	-1.854
93	-1.806
105	-1.751
112	-1.703
123	-1.640
130	-1.586
139	-1.521*
145	-1.471
155	-1.388
160	-1.339
169	-1.272
174	-1.214
181	-1.138
187	-1.098
194	-1.026*
199	-0.977
206	-0.922
210	-0.863
218	-0.802
222	-0.751
229	-0.681
233	-0.637
240	-0.572
244	-0.519*
250	-0.454
255	-0.401*
262	-0.332*
266	-0.277*
273	-0.205
CURVE 17	
83	-1.643
93	-1.597
105	-1.519
113	-1.476
123	-1.413
130	-1.369
139	-1.306
146	-1.263*
155	-1.197
160	-1.155
169	-1.092
174	-1.041*
182	-0.985
187	-0.946*
194	-0.879*
199	-0.841*
206	-0.781
211	-0.741*
218	-0.677*
222	-0.631*
229	-0.574*
233	-0.526*
240	-0.474*
245	-0.429
250	-0.368*
255	-0.327
261	-0.268*
266	-0.226
273	-0.168*
CURVE 18‡	
173	-1.135*
183	-1.057*
193	-0.977*
203	-0.898
213	-0.817
223	-0.732*
233	-0.643*
243	-0.552
253	-0.456
263	-0.353
273	-0.243*
283	-0.125
293	0.000*
303	0.137
313	0.304
323	0.511*
333	0.757
343	1.046
353	1.364
363	1.715
373	2.121
383	2.589
393	3.116
CURVE 19‡	
173	-1.558*
183	-1.475*
193	-1.389
203	-1.298*
213	-1.203
223	-1.102*
233	-0.992*
243	-0.871*
253	-0.740
263	-0.579
273	-0.391*
283	-0.199*
293	0.000*
303	0.223*
313	0.530
323	0.968*
333	1.509
343	2.281
353	3.151
363	4.649
373	7.245
CURVE 20*, ‡	
173	-1.559
183	-1.476
193	-1.389
203	-1.298
213	-1.203
223	-1.102
233	-0.992
243	-0.871
253	-0.740
263	-0.579
273	-0.391
283	-0.199
293	0.000
303	0.223
313	0.530
323	0.968
333	1.509
343	2.281
353	3.151
363	4.649
373	7.245
CURVE 21*, ‡	
173	-1.135
183	-1.056
193	-0.977
203	-0.898
213	-0.817
223	-0.732
233	-0.643
243	-0.552
253	-0.456
263	-0.353
273	-0.243
283	-0.125
293	0.000
303	0.137
313	0.303
323	0.511
333	0.757
343	1.046
353	1.364
363	1.715
373	2.121
383	2.588
393	3.116
CURVE 22	
73	-3.312
98	-3.190
123	-2.893
148	-2.595
173	-2.149
198	-1.730
223	-1.298
248	-0.851
273	-0.351*
293	0.000*
298	0.162*
323	0.689*
348	1.514
373	2.352*
398	3.406
412	4.163
CURVE 23	
73	-0.829
98	-0.829
123	-0.829
148	-0.728
173	-0.728
198	-0.566
223	-0.465
248	-0.243
273	0.000*
293	0.000*
298	0.000*
323	0.000
348	0.101
373	0.101
398	0.121
412	0.121

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 400. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLYETHYLENE

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
89	52.2
95	54.1
100	57.2
105	59.5
109	62.4
115	63.6
119	65.9
123	67.8
128	70.0
132	72.3
136	75.0
141	77.1
145	80.0
146	75.5
149	81.6
152	84.4
156	86.9
160	88.7
164	91.0
167	93.1
171	95.0
175	96.8
178	97.5*
182	99.0
184	99.8*
188	100.5
193	101.7
195	103.0
198	104.6*
201	105.9
203	118.0
204	107.2
208	110.3
211	113.3
214	116.8
217	119.4
220	121.6
223	122.9
226	125.2
229	126.8
234	135.2
237	142.2
240	145.9
244	152.1
246	156.1

T	α
CURVE 1 (cont.)‡	
248	157.9
251	159.1
254	160.7*
257	162.0
259	165.0*
262	168.2
264	173.0
266	173.6*
267	174.3*
270	175.8
272	175.8*
275	175.8
278	175.2*
280	174.3
283	173.8
285	174.0*
288	175.2
290	177.4
293	179.3
CURVE 2‡	
97	50.2
103	54.1
107	58.5
113	63.5
117	67.2*
121	71.9
125	75.8
130	78.8
135	81.4
139	84.1
143	86.1
147	87.0
150	87.4*
154	86.8*
158	86.5*
162	87.1
166	88.0
169	89.8
173	91.7
176	93.0
180	93.0
183	93.2
186	93.7*

T	α
CURVE 2 (cont.)‡	
190	95.3
193	97.6
196	100.4
200	103.6
204	95.0
206	102.5
209	105.6
212	107.5
215	111.1
218	113.6
221	116.1
224	118.5
227	121.7
230	125.6
233	130.7
236	135.5*
239	141.1
241	132.5
241	142.2
245	144.8
247	146.4
250	148.9
253	151.2
255	154.2
258	156.8
261	158.8
265	160.2
265	171.1
269	173.4
272	173.8
284	170.6
287	168.1
289	167.4
293	164.9
CURVE 18‡	
173	76.88
183	80.21
193	78.54
203	80.21
213	81.87
223	88.19
233	90.19
243	91.19

T	α
CURVE 18 (cont.)‡	
253	99.84
263	106.83
273	112.82
283	123.47
293	126.80
303	147.04*
313	186.13*
323	228.22*
333	264.31*
343	313.40*
353	322.49*
363	380.59*
373	430.68*
383	504.53*
393	549.79*
CURVE 19‡	
173	80.46
183	85.58
193	87.28
203	94.10
213	97.51
223	104.33
233	114.56
243	127.86
253	134.67
263	186.16
273	190.25
283	193.32
293	205.30
303	240.85*
313	372.67*
323	504.48*
333	576.30*
343	967.61*
353	773.04*
363	2221.95*
373	2970.77*
CURVE 20*,‡	
173	80.5
183	85.6
193	87.3

T	α
CURVE 20 (cont.)*,‡	
203	94.1
213	97.5
223	104.3
233	114.6
243	127.9
253	134.7
263	186.2
273	190.3
283	193.3
293	205.3
303	240.9
313	372.7
323	504.5
333	576.3
343	967.6
353	773.0
363	2222.0
373	2970.8
CURVE 21*,‡	
173	76.9
183	80.2
193	78.5
203	80.2
213	81.6
223	88.2
233	90.2
243	91.2
253	99.8
263	106.8
273	112.8
283	123.5
293	126.8
303	147.0
313	186.1
323	228.2
333	264.3
343	313.4
353	322.5
363	380.6
373	430.7
383	504.5
393	549.8

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 401. THERMAL LINEAR EXPANSION OF POLYETHYLENE CHLOROSULFONATE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	538	Weitzel, D.H., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1963	L	76-296	Hypalon 5-20	Specimen obtained from DuPont; cured 25 min at 427 K; zero-point correction of -0.060%.

DATA TABLE 401. THERMAL LINEAR EXPANSION OF POLYETHYLENE CHLOROSULFONATE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
76	-1.696
80	-1.673
100	-1.582
120	-1.482
140	-1.394
160	-1.299
180	-1.217
200	-1.125
220	-1.018
240	-0.866
260	-0.620
280	-0.258
293	0.000
296	0.060

*No figure given.

SPECIFICATION TABLE 402. THERMAL LINEAR EXPANSION OF POLYETHYLENE GLYCOL DIMETHACRYLATE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	541	Acitelli, M.A., Gumby, W.L., and Naujokas, A.A.	1966	I	295-331		Sample suitably worked to form a tripod placed in furnace of instrument.

DATA TABLE 402. THERMAL LINEAR EXPANSION OF POLYETHYLENE GLYCOL DIMETHACRYLATE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
295	0.016
311	0.146
331	0.346

*No figure given.

SPECIFICATION TABLE 403. THERMAL LINEAR EXPANSION OF POLYTETRAETHYLENE GLYCOL DIMETHACRYLATE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	541	Acitelli, M. A., Gumby, W. L., and Naujokas, A. A.	1966	I	294-331		Sample suitably worked to form a tripod placed in the furnace of instrument.

DATA TABLE 403. THERMAL LINEAR EXPANSION OF POLYTETRAETHYLENE GLYCOL DIMETHACRYLATE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
294	0.006
307	0.092
331	0.342

*No figure given.

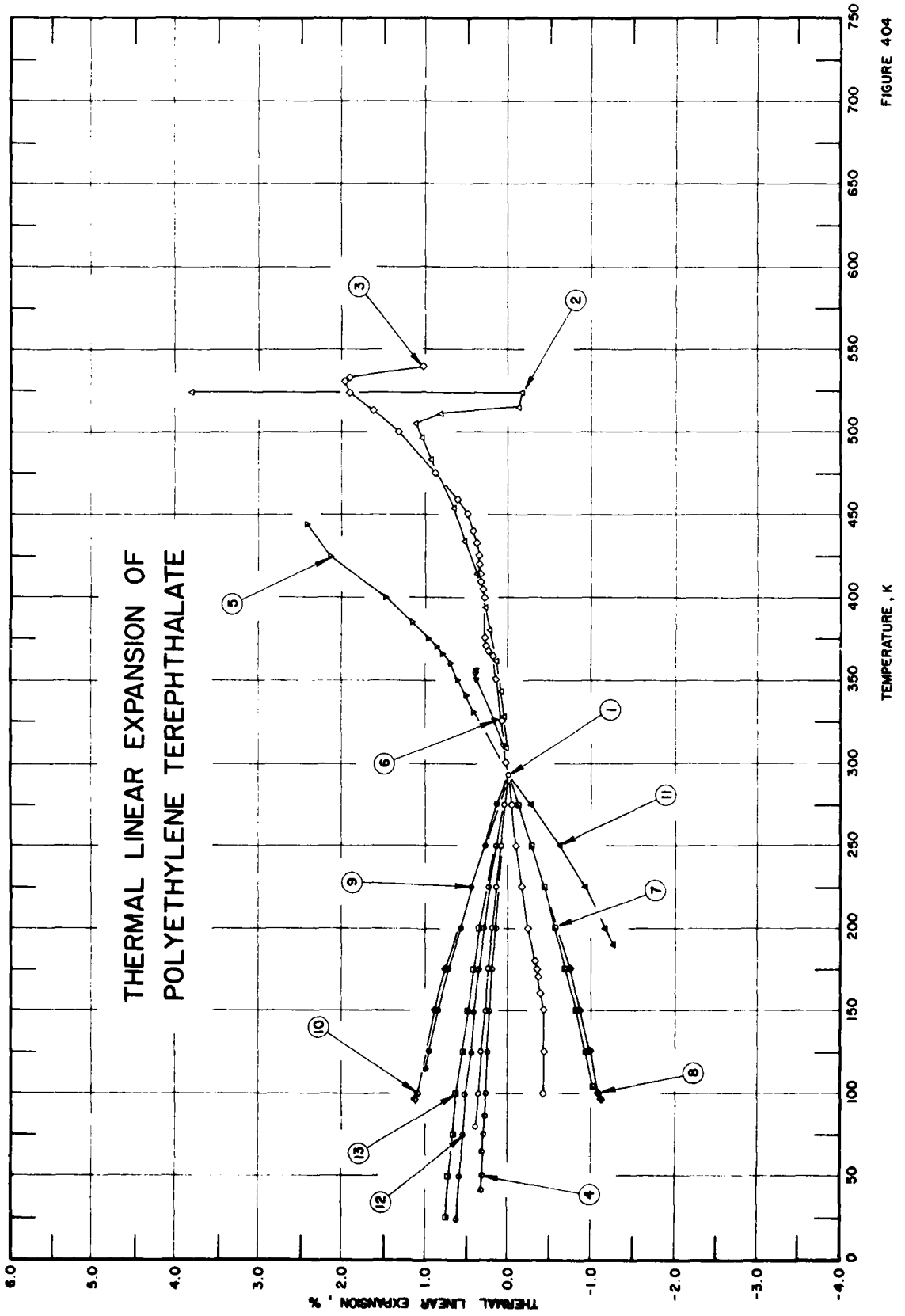

THERMAL LINEAR EXPANSION OF
POLYETHYLENE TEREPHTHALATE
THERMAL LINEAR EXPANSION , %
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
TEMPERATURE , K
1
2
3
4
5
6
7
8
9
10
11
12
13

FIGURE 404

SPECIFICATION TABLE 404. THERMAL LINEAR EXPANSION OF POLYETHYLENE TEREPHTHALATE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1048	Schramm, R.E., Clark, A.F., and Reed, R.P.	1973	L	80-293	Mylar	Specimen of length 10.16 cm, diameter 0.95 cm; total error ≤ 5%; investigator, Bailey, C.D.; Lockheed Aircraft Corp., Rept. No. ER-5682 (1962).
2	1048	Schramm, R.E., et al.	1973	L	293-524	Mylar	Film heat-stretched then heated from 293 to 498 K; investigator, Yano, Y.; Butsuri 27, 274 (1958).
3	1048	Schramm, R.E., et al.	1973	L	100-540	Mylar	Specimen of thickness 0.32 cm; flat tipped quartz probe on DuPont 940 Thermo-mechanical Analyzer; investigator, Miller, G.W.; Proceedings of the American Chemical Society Symposium on Analytical Calorimetry, San Francisco, Eds. Porter, R.S., Johnson, J.F. (Plenum Press, New York, 1968), pg. 71.
4	1032	Caren, R.P., Coston, R.M., Holmes, A.M.C., and Dubus, F.	1965		42-293	Mylar	Specimen of length 5.08 cm, diameter 0.63 in., thickness 0.003 cm; rolled into tight cylinders; 5% maximum data scatter.
5	1033	Thompson, A.B. and Woods, D.W.	1956		331-444	Terylene filament yarn	Specimen birefringence 0.22; thermal expansion measurements made by observing change of length of specimen suspended by its own weight inside insulated metal jacket; birefringence decay observed using hot-stage microscope fitted with Babinet compensator; zero-point correction of 0.418% determined by graphical extrapolation.
6	1033	Thompson, A.B. and Woods, D.W.	1956		293-357		Specimen similar to the above, except birefringence 0.00.
7	1034	Haldon, R.A., Schell, W.J., and Simha, R.	1967	L	104-293	Mylar	Specimen as received; 19,500 mol wt.; quoted accuracy ± 5%.
8	1034	Haldon, R.A., et al.	1967	L	97-293	Mylar	Mylar 35% crystalline; 19,500 mole wt.
9	1034	Haldon, R.A., et al.	1967		115-293	Mylar	Specimen as received; 1.350 mol. wt.
10	1034	Haldon, R.A., et al.	1967		97-293	Mylar	Mylar of 35% crystalline; 1,350 mol. wt.
11	574	Haskins, J.F., Campbell, M.D., Hertz, J., and Percy, J.L.	1964	L	190-293	Mylar	Thermal linear expansion measured perpendicular to film.
12	574	Haskins, J.F., et al.	1964	L	24-293	Mylar	Similar to the above specimen, except in Mylar trans. direction.
13	574	Haskins, J.F., et al.	1964	L	25-293	Mylar	Similar to the above specimen, except in Mylar long. direction.

DATA TABLE 404. THERMAL LINEAR EXPANSION OF POLYETHYLENE TEREPHTHALATE

(Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %)

T	$\Delta L/L_0$
CURVE 1	
80	0.400
100	0.368
125	0.329
150	0.286
175	0.245
200	0.197
225	0.146
250	0.095
275	0.042
293	0.000
CURVE 2	
293	0.000*
309	0.018
328	0.050
343	0.088
362	0.142
380	0.218
394	0.280
414	0.390
434	0.527
454	0.670
483	0.915
497	1.047
505	1.112
511	0.815
515	-0.125
524	-0.171
523	0.815*
524	3.803
CURVE 3	
100	-0.403
125	-0.403
150	-0.403
161	-0.378
170	-0.360
175	-0.330
180	-0.301
200	-0.229
225	-0.164
250	-0.098
275	-0.033
293	0.000*
CURVE 3 (cont.)	
300	0.024
325	0.087
350	0.153
364	0.198
367	0.246
370	0.274
375	0.292
400	0.297
405	0.303
409	0.334
414	0.348
420	0.348
425	0.355
433	0.392
440	0.434
450	0.500
459	0.621
475	0.891
500	1.324
513	1.637
524	1.925
531	1.981
533	1.914
540	1.037
CURVE 4	
42	0.316
50	0.312
65	0.309
75	0.301
87	0.294
100	0.285
125	0.262
150	0.235
175	0.202
200	0.165
225	0.119*
250	0.074*
275	0.031*
293	0.000*
CURVE 5	
331	0.418
340	0.518
350	0.608
360	0.698
366	0.798
370	0.868
375	0.958
385	1.148
400	1.498
425	2.128
444	2.418
CURVE 6	
293	0.000*
300	0.021*
310	0.051
325	0.152
350	0.394
353	0.400
356	0.398
357	0.393*
CURVE 7	
104	-1.013
125	-0.933
150	-0.810
175	-0.689
200	-0.561
225	-0.433
250	-0.286
275	-0.127
293	0.000*
CURVE 8	
97	-1.106
100	-1.095
125	-0.992
150	-0.868
175	-0.741
200	-0.597*
225	-0.452*
250	-0.286*
275	-0.127*
293	0.000*
CURVE 9	
115	1.000
125	0.953
150	0.845
175	0.715
200	0.589
225	0.443
250	0.286
275	0.127
293	0.000*
CURVE 10	
97	1.106
100	1.095
125	0.992*
150	0.868
175	0.741
200	0.597*
225	0.452*
250	0.286*
275	0.127*
293	0.000*
CURVE 11	
190	-1.250
200	-1.163
225	-0.912
250	-0.612
275	-0.266
293	0.000*
CURVE 12	
24	0.631
50	0.599
75	0.554
100	0.507
125	0.452
150	0.402
175	0.351
CURVE 12 (cont.)	
200	0.292
225	0.232
250	0.163
275	0.072*
293	0.000*
CURVE 13	
25	0.767
50	0.731
75	0.683
100	0.628
125	0.566
150	0.500
175	0.420
200	0.342
225	0.257*
250	0.163*
275	0.072*
293	0.000*

* Not shown in figure.

SPECIFICATION TABLE 405. THERMAL LINEAR EXPANSION OF COPOLY(ETHYLENE - PROPYLENE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	544	Haldon, R.A. and Simha, R.	1968	L	26-113	E - P	Specimen containing 49% ethylene with 2.6% ethylene and 1.6% propylene crystallinity; furnished by U.S. Rubber Co.; molded to shape under pressure of 5000 psi; expansion measured in liquid helium cryostat; this curve is here reported using the first given temperature (26 K) as reference temperature at which $\Delta L/L_0 = 0$.
2*	544	Haldon, R.A. and Simha, R.	1968	L	98-195	E - P	The above specimen; expansion measured in liquid nitrogen cryostat; this curve is here reported using the first given temperature (98 K) as reference temperature at which $\Delta L/L_0 = 0$.

*No figure given.

DATA TABLE 405 THERMAL LINEAR EXPANSION OF COPOLY(ETHYLENE - PROPYLENE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*, †, ‡		CURVE 1 (cont.)*, †, ‡		CURVE 1 (cont.)*, †, ‡		CURVE 2*, †, ‡		CURVE 2 (cont.)*, †, ‡		CURVE 2 (cont.)*, †, ‡	
26	0.000	65	0.117	92	0.243	98	0.000	140	0.277	174	0.554
32	0.013	68	0.133	95	0.257	104	0.031	144	0.309	178	0.587
38	0.024	72	0.148	98	0.272	109	0.063	148	0.341	181	0.615
42	0.036	75	0.163	100	0.286	113	0.089	151	0.365	184	0.642
47	0.048	78	0.177	103	0.299	118	0.124	156	0.401	187	0.674
52	0.061	81	0.189	105	0.309	122	0.151	160	0.431	190	0.703
55	0.072	84	0.203	107	0.323	127	0.185	164	0.465	193	0.727
59	0.087	87	0.217	110	0.340	131	0.212	167	0.492	195	0.750
62	0.101	89	0.229	113	0.352	136	0.248	170	0.522		
65	0.133										

DATA TABLE 405. COEFFICIENT OF THERMAL LINEAR EXPANSION OF COPOLY(ETHYLENE - PROPYLENE)

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α
CURVE 1*, ‡		CURVE 1 (cont.)*, ‡		CURVE 2*, ‡		CURVE 2 (cont.)*, ‡	
26	17.9	78	45.7	98	57.0	156	79.8
32	20.3	81	46.1	104	59.7	160	80.8
38	23.1	84	47.0	109	61.6	164	82.1
42	24.8	87	47.7	113	64.5	167	83.8
47	27.1	89	48.8	118	66.1	170	85.2
52	30.2	92	49.7	122	68.9	174	87.6
55	37.3	95	50.9	127	70.6	178	89.8
59	43.2	98	51.8	131	72.0	181	89.8
62	46.1	100	52.8	136	74.7	184	92.0
65	47.7	103	52.8	140	75.7	187	94.4
68	47.0	105	53.3	144	76.0	190	94.4
72	46.3	107	54.3	148	76.0	193	95.4
75	44.4	110	54.3	151	78.9	195	96.7
		113	54.3				

*No figure given.
†This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡Author's data for coeff. .ent of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 406. THERMAL LINEAR EXPANSION OF POLY(TRIFLUORO-CHLOROETHYLENE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	548	Laquer, H. L. and Head, E. L.	1952	L	0-380	Fluorothene	Rod specimen 5 in. diameter; molded by Union Carbon and Carbide at Oak Ridge, Tenn. in 1948; milky appearance; expansion measured perpendicular to rod axis; zero-point correction of -0.136% determined by graphical interpolation.

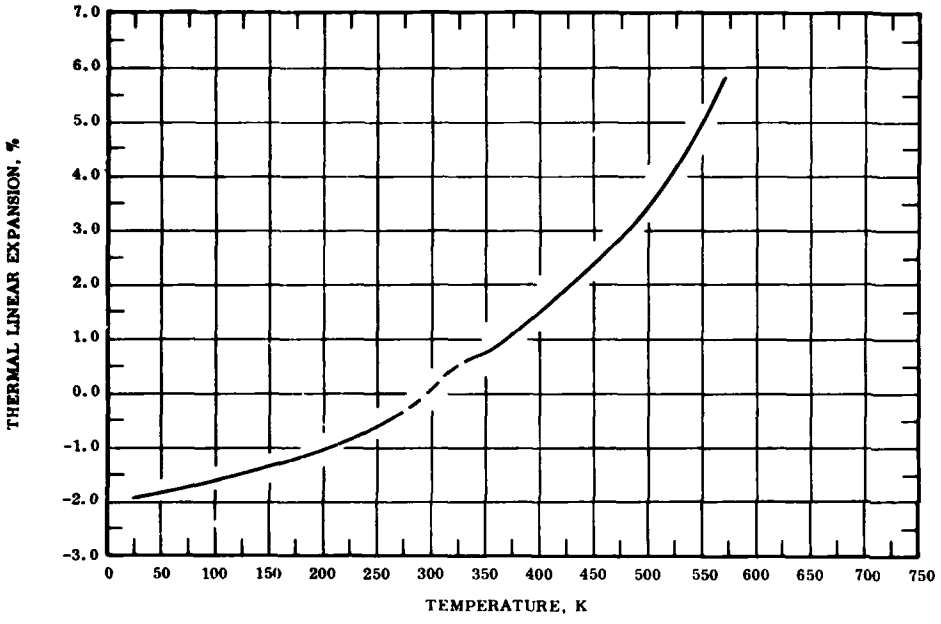
DATA TABLE 406. THERMAL LINEAR EXPANSION OF POLY(TRIFLUORO-CHLOROETHYLENE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 1 (cont.)*	
0	-1.136	300	0.050
20	-1.116	320	0.220
40	-1.072	340	0.425
60	-1.021	360	0.660
80	-0.964	380	0.920
100	-0.902		
120	-0.845		
140	-0.765		
160	-0.688		
180	-0.611		
200	-0.501		
220	-0.426		
240	-0.326		
260	-0.216		
273	-0.136		
280	-0.092		

*No figure given.

FIGURE AND TABLE NO. 407R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF POLY(TETRAFLUOROETHYLENE)



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
25	-1.91	27
50	-1.82	30
75	-1.70	34
100	-1.60	38
125	-1.48	45
150	-1.34	56
175	-1.20	70
200	-1.04	85
225	-0.83	95
250	-0.59	102
275	-0.31†	116
285	-0.18†	135
293	0.00†	525
300	0.17†	124
305	0.27†	122
310	0.33†	121
315	0.40†	120
320	0.45†	120
325	0.51†	119
330	0.56†	118
340	0.66	120
350	0.79	121
375	1.14	131
400	1.51	147
425	1.92	167
450	2.35	192
475	2.85	222
500	3.42	258
525	4.13	305
550	5.00	387
570	5.80	566

† Provisional values.

REMARKS

The recommended values are based on the data for annealed high density (2.2 g cm^{-3}) Teflon samples (curves 16, 23, 27). The first order transition between 293 K and 303 K results in anomalous expansion values and in a pronounced peak in the data for the coefficient of thermal expansion. The scatter of the experimental data is due to the various methods of sample preparation. These values are considered accurate to within ± 5% except those near the transition point, which are considered accurate to within ± 15%. These values are represented approximately by the following equations:

$$\Delta L/L_0 = -2.52 + 1.37 \times 10^{-2}\, T - 6.06 \times 10^{-5}\, T^2 + 1.46 \times 10^{-7}\, T^3 \quad (25\text{–}293\ K)$$

$$\Delta L/L_0 = -9.60 + 1.51 \times 10^{-2}\, T + 1.64 \times 10^{-4}\, T^2 - 3.52 \times 10^{-7}\, T^3 \quad (293\text{–}340\ K)$$

$$\Delta L/L_0 = -17.07 + 0.12\, T - 2.75 \times 10^{-4}\, T^2 + 2.45 \times 10^{-7}\, T^3 \quad (340\text{–}570\ K)$$

The tabulated values for the coefficient of thermal expansion are derived from the selected experimental data (curves 13, 22 and 23) and are considered accurate to about ± 10% with the exception of those near the transition point which are more uncertain.

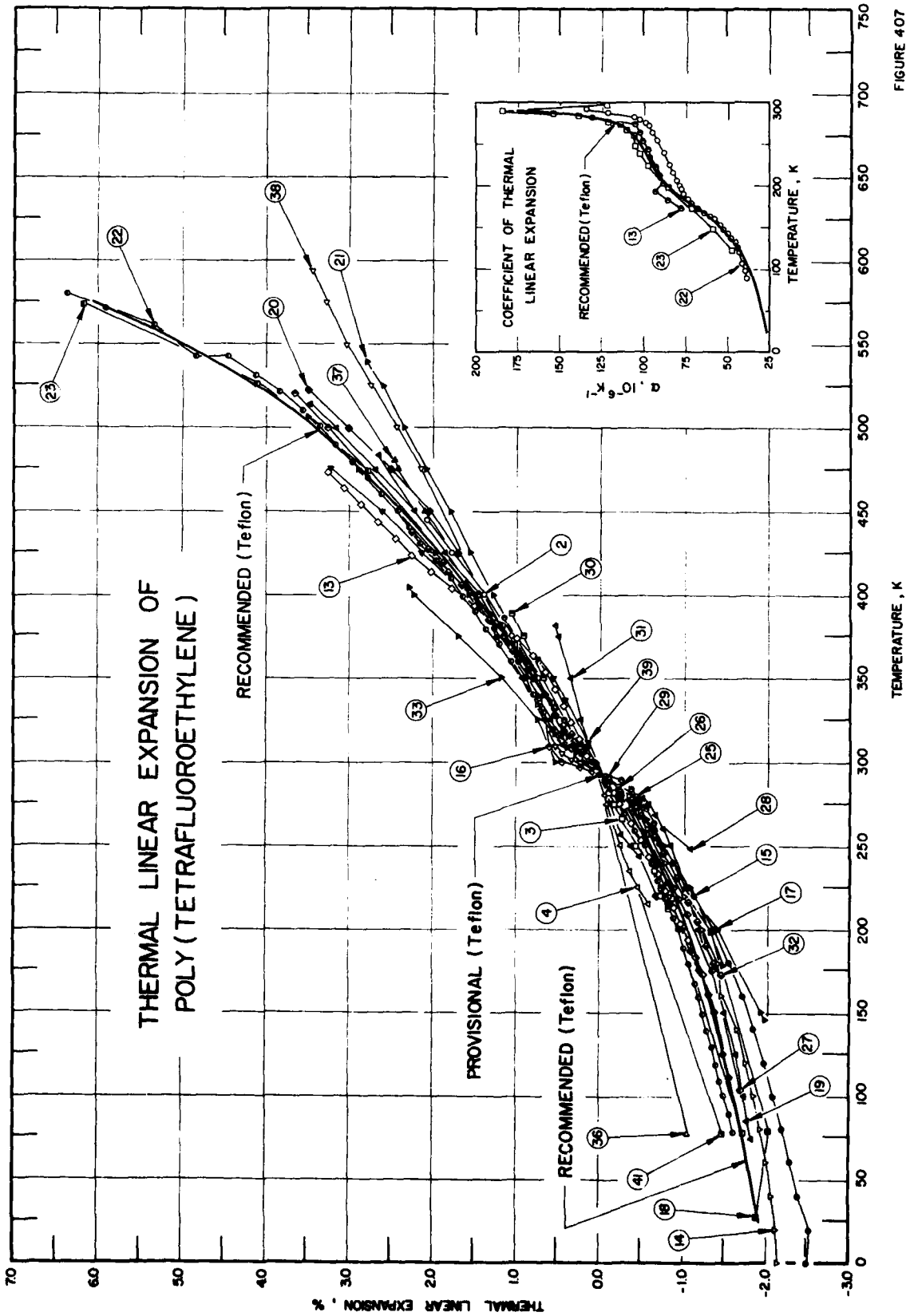

THERMAL LINEAR EXPANSION OF
POLY(TETRAFLUOROETHYLENE)
RECOMMENDED (Teflon)
PROVISIONAL (Teflon)
RECOMMENDED (Teflon)
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
COEFFICIENT OF THERMAL
LINEAR EXPANSION
RECOMMENDED (Teflon)
α, 10⁻⁶ K⁻¹
TEMPERATURE, K

FIGURE 407

SPECIFICATION TABLE 407. THERMAL LINEAR EXPANSION OF POLY(TETRAFLUOROETHYLENE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	556	Araki, Y.	1965	L	272-445	Polyflon M-11	Cylindrical specimen of length 20 mm, diameter 10 mm; powder prepared by Daikin Kogyo; pressed under 300 kg cm^{-2}; sintered at 360 C in air 2 hr; expansion measured with specimen immersed in oil bath.
2	1035	Araki, Y.	1965		322-444	Teflon 5	Specimen of length 4.0 cm, diameter 1.5 cm; sp. gr. 2.1758; 59% crystal; unbonded type strain gauge; zero-point correction is 0.308% determined by graphical interpolation.
3	1035	Araki, Y.	1965		220-282	Teflon 6	Specimen of length 4.0 cm, diameter 1.5 cm; sp. gr. 2.2088; 59% crystal; unbonded type strain gauge; zero-point correction is 0.026% determined by graphical extrapolation.
4	1035	Araki, Y.	1965		215-281	Teflon 6	Similar to the above specimen; sp. gr. 2.2470; 82% crystal; zero-point correction is 0.034% determined by graphical extrapolation.
5*	557	Hirakawa, S. and Takemura, T.	1969	B	283-308		Specimen 9.96 mm initial length; expansion measured under 1 kg cm^{-2} pressure.
6*	557	Hirakawa, S. and Takemura, T.	1969	B	291-315		Specimen 9.92 mm initial length; expansion measured under 430 kg cm^{-2} pressure.
7*	557	Hirakawa, S. and Takemura, T.	1969	B	291-315		Specimen 9.84 mm initial length; expansion measured under 1440 kg cm^{-2} pressure.
8*	557	Hirakawa, S. and Takemura, T.	1969	B	323-358		Specimen 9.70 mm initial length; expansion measured under 4500 kg cm^{-2} pressure.
9*	557	Hirakawa, S. and Takemura, T.	1969	B	300-390		Specimen 9.68 mm initial length; expansion measured under 5200 kg cm^{-2} pressure.
10*	557	Hirakawa, S. and Takemura, T.	1969	B	300-417		Specimen 9.66 mm initial length; expansion measured under 5 kg cm^{-2} pressure.
11*	557	Hirakawa, S. and Takemura, T.	1969	B	300-422		Specimen 9.64 mm initial length; expansion measured under 6000 kg cm^{-2} pressure.
12*	557	Hirakawa, S. and Takemura, T.	1969	B	300-439		Specimen 9.63 mm initial length; expansion measured under 6500 kg cm^{-2} pressure.
13	171	Asay, J.R., Urzendowski, S.R., and Guenther, A.H.	1968		173-473		Specimen of density 2.186 g cm^{-3}; mp 602 K.
14	548	Laquer, H.L. and Head, E.L.	1952	L	0-340	Teflon	Rod specimen 2.54 cm long; extruded by U.S. Gasket Co.; expansion measured perpendicular to rod direction; reported error ± 2-5%; zero-point correction is -0.428% determined by graphical interpolation.
15	548	Laquer, H.L. and Head, E.L.	1952	L	0-380	Teflon	Similar to the above specimen; extruded by Graof Engineering Co.; expansion measured parallel to rod direction; reported error ± 2-5%; zero-point correction is -0.452% determined by graphical interpolation.
16	1036	Gillespie, L.H., Saxton, D.O., and Chapman, F.M.	1960		111-520	Teflon I	No details given; zero-point correction is 0.258%.
17	1037	Koo, G.P., Jones, E.D., Riddell, Riddell, M.N., and O'Toole, J.L.	1965		146-506	Halon G-80	No details given; zero-point correction is 0.123%.
18	1038	Belton, J.H., Godby, L.L., and Taft, B.L.	1960	L	27-296	Teflon	Specimen of length 10.7 cm; zero-point correction is 0.048%.

* Not shown in figure.

SPECIFICATION TABLE 407. THERMAL LINEAR EXPANSION OF POLY(TETRAFLUOROETHYLENE) (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
19	1039	Orgarkiewicz, R.M.	1970		73-514	Fluon	Specimen expansion measured perpendicular to direction of molding pressure.
20	1039	Orgarkiewicz, R.M.	1970		220-522	Fluon	Specimen measured parallel to direction of molding pressure.
21	1040	Beel, V.S. and Markovich, V.Y.	1963		293-540	Fluoroplast IV	Specimen of length 2.5-5.0 cm, diameter 1.0 cm; samples heated at 1, 5, and 10 K min^{-1} with very little difference.
22	1041	Leskina, I.E. and Novikova, S.I.	1959		78-580	Fluoroplast IV	No details given.
23	1042	Kirby, R.K.	1956		77-574	Teflon	Specimen of length 7.6 cm, diameter 1.27 cm; extruded, annealed; sp. gr. 2.162 at 298 K; fused quartz tube and dial-indicator method used, 0.00025 cm graduations on indicator; zero-point correction is 0.160%.
24*	1043	Beecroft, R.I. and Swenson, C.A.	1959		274-316	Teflon	Rod specimen of length 2.43 cm; 68% crystal; sp. gr. 2.25; fused-quartz tube and dial indicator method; average heating and cooling rate 0.2 K h^{-1} with a maximum of 0.6 K h^{-1}; zero-point correction of 0.600%.
25	1043	Beecroft, R.I. and Swenson, C.A.	1959		273-293	Teflon	Thermal linear expansion measurements made with average, not constant temperature change of 0.2 deg/hr with maximum of 0.6 deg/hr; zero-point correction is 0.065%.
26	1043	Beecroft, R.I. and Swenson, C.A.	1959		273-293	Teflon	Similar to the above specimen; zero-point correction is 0.257%.
27	1034	Haldon, R.A., Schell, W.J., and Simha, R.	1967	L	104-327	Teflon	Specimen of 52% crystal; quoted probable accuracy ± 5%.
28	1044	Fel'dman, R.I. and Sokolov, S.I.	1965		248-483	Fluoroplast IV	Specimen of length 10 cm, width 1 cm, thickness 0.2 cm; nonoriented and unquenched; strips placed vertically in dynamometer operated as a dilatometer.
29	1045	Sidorovich, A.V. and Kuvshinskii, E.V.	1959		251-386	Teflon	Thermal linear expansion of specimen measured perpendicular to rolling direction; heating; zero-point correction is -0.118%.
30	1045	Sidorovich, A.V. and Kuvshinskii, E.V.	1959		389-212	Teflon	Similar to the above specimen except cooling.
31	1045	Sidorovich, A.V. and Kuvshinskii, E.V.	1959		244-381	Teflon	Thermal linear expansion of specimen measured parallel to rolling direction; heating and cooling; zero-point correction is 0.012%.
32	1046	Ohzawa, Y. and Wada, Y.	1964		172-437		No details given; zero-point correction is -0.437%.
33*	1046	Ohzawa, Y. and Wada, Y.	1964		178-404		Plate specimen of thickness 0.6 cm; 68% crystal; sp. gr. 2.161 at 298 K; differential transformer; zero-point correction is 0.064%.
34*	1046	Ohzawa, Y. and Wada, Y.	1964		226-457	Stretched PTFE film	Thermal linear expansion measured parallel; zero-point correction is 0.110%.
35*	1046	Ohzawa, Y. and Wada, Y.	1964		227-457		Similar to the above except perpendicular; zero-point correction is -0.730%.
36	1047	Wisander, D.W. and Johnson, R.L.	1969		77,300		Specimen of length 2.54 cm, diameter 0.95 cm; submerged in liquid N_2 then measured with micrometer; measurement repeated 6-8 times until no further contraction noted; zero-point correction is 0.047% determined by graphical interpolation.

* Not shown in figure.

SPECIFICATION TABLE 407. THERMAL LINEAR EXPANSION OF POLY(TETRAFLUOROETHYLENE) (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
37		Schramm, R.E., Clark, A.F., and Reed, R.P.	1973	L	293–480	Teflon TF 1	Specimen of length 5.08 cm, diameter 0.64 cm; sp. gr. 2.14; molded under 4,000 psi; cured at 639 K and cooled at 56 K h^{-1}; zero-point correction is 0.054%; investigators: Rudner, M.A., Graeff, R.F., Bertolet, Jr., E.C.; Navy Dept. Bureau of Ships Electronics Div. (AD 45199) (1954).
38		Schramm, R.E., et al.	1973	L	220–593	Teflon film	No details given; zero-point correction is -0.064%; investigator: Yano, Y.; Oyo Butsuri, 27, 274 (1958).
39		Schramm, R.E., et al.	1973		174–475	Teflon	Specimen of length 0.64 cm, diameter 0.64 cm; DuPont 940 amp thermo mechanical analyzer; total probable error ±2.5%; zero-point correction is 0.015%.
40*		Schramm, R.E., et al.	1973		0–180	Teflon	Thin film; vapor deposited gold electrodes; zero-point correction is 0.710% determined by graphical extrapolation; investigator: Mathes, K.N.; 20th Annual Technical Conference (Atlantic City) 10, xx-3 (1964).
41		Schramm, R.E., et al.	1973		77,300	Teflon	Specimen of length 2.5 cm, diameter 2.5 cm; zero-point correction is 0.047% determined by graphical interpolation; investigators: Salinger, G.L. and Wheatley, J.C.; Rev. Sci. Instr. 32, 872 (1961).

* Not shown in figure.

DATA TABLE 407. THERMAL LINEAR EXPANSION OF POLY(TETRAFLUOROETHYLENE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
272	-1.000
274	-0.926
277	-0.818
282	-0.606
286	-0.491
289	-0.321
292	-0.153
294	0.153
295	0.506
298	0.632
301	0.774
303	0.859
303	0.947
306	1.009
309	1.126
312	1.265
328	1.838
361	3.038
386	3.976
411	4.979
416	5.188
420	5.374
431	5.894
445	6.512
CURVE 2	
322	0.435
325	0.481
350	0.731
375	1.052
400	1.389
425	1.771
444	2.068
CURVE 3	
220	-0.722
230	-0.639
250	-0.436
266	-0.274
275	-0.190
282	-0.116

T	$\Delta L/L_0$
CURVE 4	
215	-0.580
225	-0.451
235	-0.366
250	-0.259
275	-0.093
281	-0.062
CURVE 5*	
283	-0.363
287	-0.300
290	-0.221
291	-0.149
292	-0.075
295	0.149
297	0.191
302	0.271
303	0.309
308	0.378
CURVE 6*	
291	-0.007
294	0.018
296	0.038
297	0.071
298	0.125
300	0.203
301	0.329
302	0.354
307	0.364
312	0.380
315	0.384
CURVE 7*	
301	0.014
306	0.023
308	0.035
310	0.058
311	0.106
314	0.289
3[illegible]	0.307
323	0.321

T	$\Delta L/L_0$
CURVE 8*	
323	0.047
332	0.061
339	0.084
343	0.097
344	0.126
346	0.186
348	0.190
358	0.189
CURVE 9*	
300	-0.017
336	-0.103
342	-0.132
345	-0.159
347	-0.279
350	-0.446
352	-0.453
357	-0.428
361	-0.386
367	-0.292
375	-0.149
379	-0.089
382	-0.069
390	-0.049
CURVE 10*	
300	-0.011
331	-0.061
338	-0.085
341	-0.126
344	-0.221
346	-0.436
348	-0.648
352	-0.663
356	-0.660
362	-0.630
367	-0.577
372	-0.493
378	-0.361
383	-0.203
387	-0.138
393	-0.083
399	-0.052

T	$\Delta L/L_0$
CURVE 10 (cont.)*	
406	-0.035
417	-0.017
CURVE 11*	
300	-0.023
325	-0.104
330	-0.146
333	-0.194
336	-0.366
339	-0.863
341	-0.921
346	-0.952
357	-0.957
366	-0.947
378	-0.909
386	-0.860
394	-0.786
397	-0.720
401	-0.614
409	-0.225
412	-0.109
416	-0.113
422	-0.077
CURVE 12*	
300	-0.024
312	-0.066
318	-0.098
320	-0.169
324	-0.381
327	-0.839
330	-0.916
335	-0.967
340	-0.992
354	-1.001
370	-1.000
383	-0.986
398	-0.947
407	-0.910
414	-0.854
418	-0.802
423	-0.725
426	-0.632

T	$\Delta L/L_0$
CURVE 12 (cont.)*	
429	-0.413
432	-0.251
435	-0.171
439	-0.126
CURVE 13‡	
173	-1.237
183	-1.155
193	-1.064
203	-0.973
213	-0.882
223	-0.790
233	-0.694
243	-0.597
253	-0.498
263	-0.396
273	-0.292
283	-0.174
293	0.000
303	0.156
313	0.249*
323	0.340*
333	0.435
343	0.536
353	0.652
363	0.800
373	0.997
383	1.244
393	1.501
403	1.761
413	2.017
423	2.249
433	2.463
443	2.666
453	2.862
463	3.053
473	3.242
CURVE 14	
0	-2.143
20	-2.118
40	-2.068
60	-2.003

T	$\Delta L/L_0$
CURVE 14 (cont.)	
80	-1.928
100	-1.848
120	-1.758
140	-1.658
160	-1.543
180	-1.403
200	-1.218
220	-1.003
240	-0.788
260	-0.573
273.2	-0.428
280	-0.358
300	0.192*
320	0.477
340	0.752
CURVE 15	
0	-2.497
20	-2.532
40	-2.382
60	-2.297
80	-2.197
100	-2.087
120	-1.972
140	-1.842
160	-1.712
180	-1.557
200	-1.367
220	-1.127
240	-0.877
260	-0.622
273.2	-0.452
280	-0.367*
300	0.198*
320	0.463*
340	0.718*
360	0.988
380	1.253
CURVE 16	
111	-1.538
125	-1.481
150	-1.368

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 407. THERMAL LINEAR EXPANSION OF POLY(TETRAFLUOROETHYLENE) (continued)

T	$\Delta L/L_0$
CURVE 16 (cont.)	
161	-1.303
175	-1.192
188	-1.091
200	-0.973*
225	-0.739*
250	-0.456*
275	-0.201*
289	-0.040*
293	0.000*
295	0.094
297	0.258
300	0.470
309	0.603
325	0.676*
338	0.736
350	0.847*
375	1.146
400	1.467
425	1.853*
450	2.273*
475	2.793*
500	3.258
520	3.638
CURVE 17	
146	-1.980
150	-1.934
200	-1.409
225	-1.102
250	-0.789
266	-0.549
275	-0.398
287	-0.148
293	0.000*
300	0.123*
308	0.380
316	0.527
325	0.641*
334	0.740
350	0.869
375	1.216*
400	1.558
425	1.979
450	2.391*
475	2.897
500	3.342*
506	3.499

T	$\Delta L/L_0$
CURVE 18	
27	-1.888
78	-2.028
198	-1.344
293	0.000*
296	0.048
CURVE 19	
73	-1.803
85	-1.776
100	-1.730
125	-1.620
150	-1.490
200	-1.182
250	-0.845
260	-0.772
268	-0.674
275	-0.579
278	-0.500
281	-0.274
287	-0.119
293	0.000*
300	0.110
303	0.290*
310	0.445
325	0.667
350	0.933
375	1.220
400	1.508
425	1.862
450	2.214
475	2.699
500	3.162
514	3.485
CURVE 20	
220	-0.688
250	-0.418*
275	-0.195*
293	0.000*
300	0.058
308	0.177
311	0.321
318	0.430
325	0.500*
350	0.796
375	1.075*

T	$\Delta L/L_0$
CURVE 20 (cont.)	
400	1.358*
425	1.701
450	2.039
475	2.500
500	3.000
522	3.500
CURVE 21	
293	0.000*
300	0.084*
319	0.408*
325	0.501*
350	0.791*
375	1.042*
400	1.265
425	1.544
450	1.794
475	2.065
500	2.328
525	2.600
540	2.796
CURVE 22	
78	-1.60
89	-1.55
100	-1.48
108	-1.44
119	-1.39
129	-1.34
139	-1.28
149	-1.23
159	-1.18
167	-1.13
179	-1.06
278	-1.00
200	-0.94
207	-0.86
219	-0.78
229	-0.69
239	-0.61
250	-0.53
259	-0.41
269	-0.29
280	-0.18*
289	-0.07
293	0.00*

T	$\Delta L/L_0$
CURVE 22 (cont.)	
299	0.27
310	0.46*
319	0.57
329	0.68
340	0.80
349	0.94*
360	1.07
370	1.20
379	1.36
385	1.50
399	1.64
410	1.78
420	1.96
431	2.13
440	2.28
450	2.41
460	2.62
470	2.79
479	2.97
490	3.16
501	3.34
510	3.56
521	3.82
531	4.10
542	4.45
542	4.82
561	5.01
571	5.39
580	6.37
CURVE 23	
77	-1.710
228	-0.810
240	-0.690
257	-0.560
270	-0.430
279	-0.260
284	-0.160*
290	-0.060*
293	0.000*
297	0.060*
300	0.160*
302	0.230
304	0.270
324	0.480*
335	0.570
349	0.750*

T	$\Delta L/L_0$
CURVE 23 (cont.)	
370	1.010
381	1.160
424	1.820*
474	2.780
526	4.090
574	6.160
CURVE 24*	
274	-5.400
289	-2.420
290	-2.280
291	-1.660
292	-0.770
293	0.000
296	0.600
300	1.430
302	1.980
308	2.870
316	3.530
CURVE 25	
273	-0.514*
273	-0.508*
274	-0.502*
275	-0.497*
276	-0.487*
277	-0.475
278	-0.464*
279	-0.451*
280	-0.435
281	-0.435*
282	-0.426*
283	-0.406*
284	-0.397*
285	-0.383*
291	-0.080
293	0.000*
CURVE 26	
273	-0.322*
273	-0.316*
274	-0.310*
275	-0.305*
276	-0.295*
277	-0.283*

T	$\Delta L/L_0$
CURVE 26 (cont.)	
278	-0.272*
279	-0.259*
280	-0.243*
281	-0.243*
282	-0.234
285	-0.215
285	-0.204*
293	0.000*
293	0.093*
CURVE 27	
104	-1.696
125	-1.601*
150	-1.486*
175	-1.334
200	-1.150*
209	-1.048
218	-0.954
225	-0.882
229	-0.810*
239	-0.596*
250	-0.499*
275	-0.243
284	-0.132
293	0.000*
300	0.164*
306	0.272*
313	0.373
325	0.511*
327	0.523
CURVE 28	
248	-1.096
275	-0.395*
290	-0.035*
293	0.000*
300	0.140*
307	0.290
315	0.456
325	0.598
339	0.800*
350	0.896*
375	1.116*
400	1.372*
425	1.707*
450	2.079*

* Not shown in figure.

DATA TABLE 407. THERMAL LINEAR EXPANSION OF POLY(TETRAFLUOROETHYLENE) (continued)

T	$\Delta L/L_0$
CURVE 28 (cont.)	
475	2.499*
483	2.650
CURVE 29	
251	-0.714
263	-0.653
272	-0.560
275	-0.531*
284	-0.397
289	-0.269
291	-0.118
293	0.000*
300	0.128*
325	0.431
350	0.707*
375	0.998*
386	1.128
CURVE 30	
389	1.057
375	0.913
350	0.683
325	0.412*
309	0.239
300	0.105*
293	0.000*
283	-0.175*
275	-0.301*
263	-0.421*
250	-0.550*
238	-0.637*
225	-0.725
212	-0.813
CURVE 31	
244	-0.488
250	-0.387
257	-0.269
275	-0.124
288	-0.033*
293	0.000*
295	0.012*
300	0.038*
325	0.210
350	0.355
375	0.504
381	0.549
CURVE 32	
172	-1.449
180	-1.377
181	-1.365*
186	-1.320*
187	-1.314*
190	-1.278
195	-1.243*
202	-1.198*
205	-1.170
208	-1.134*
212	-1.086*
216	-1.052
218	-1.028*
221	-1.004*
222	-0.994*
223	-0.978*
225	-0.961*
228	-0.948*
231	-0.915
233	-0.898*
234	-0.875*
236	-0.854*
238	-0.821*
240	-0.809*
242	-0.790*
244	-0.771*
245	-0.754
246	-0.742*
248	-0.721*
250	-0.703*
252	-0.680*
255	-0.656
257	-0.634*
261	-0.596*
261	-0.569*
264	-0.561*
264	-0.525*
267	-0.515*
268	-0.490
270	-0.470*
271	-0.455*
272	-0.443*
274	-0.418*
275	-0.401*
277	-0.384
278	-0.361*
279	-0.341*
280	-0.326*
282	-0.302*
283	-0.288*
284	-0.271*
285	-0.246*
286	-0.226*
286	-0.207*
287	-0.186*
288	-0.163*
289	-0.142*
289	-0.105*
290	-0.061*
291	-0.017*
292	-0.006*
293	0.000*
294	0.003*
294	0.022*
295	0.029*
296	0.046*
297	0.067*
299	0.083*
300	0.097*
301	0.114*
301	0.142*
303	0.160*
304	0.182*
306	0.208
307	0.231*
309	0.253*
311	0.284*
313	0.316*
316	0.343
317	0.375*
320	0.388*
322	0.413*
325	0.451*
327	0.506*
332	0.548
335	0.598*
338	0.657*
340	0.670
341	0.681*
342	0.678*
344	0.709*
344	0.728*
347	0.752*
348	0.776*
351	0.823*
353	0.846*
355	0.869
356	0.899*
357	0.910*
359	0.935*
360	0.951*
361	0.970*
363	0.991*
364	1.010*
366	1.031
367	1.053*
369	1.071*
370	1.097*
373	1.140*
374	1.158*
375	1.171*
376	1.183*
377	1.191*
377	1.206*
378	1.224*
379	1.250*
384	1.301*
385	1.310
386	1.345*
387	1.356*
388	1.366*
389	1.396*
390	1.418*
392	1.446*
394	1.446
395	1.480*
396	1.514*
399	1.547*
400	1.564*
401	1.594*
402	1.613*
404	1.635*
406	1.664
408	1.696*
410	1.746*
412	1.788*
413	1.806
414	1.829*
417	1.874*
419	1.898
420	1.930*
421	1.945*
424	2.006*
425	2.033*
427	2.063
430	2.131*
434	2.209*
437	2.255
CURVE 33	
178	-1.470
200	-1.322*
225	-1.078
250	-0.812*
266	-0.561*
275	-0.413*
284	-0.245*
293	0.000*
297	0.064*
300	0.526
325	0.738
350	1.195
375	1.704
400	2.204
404	2.279
CURVE 34*	
226	0.040
236	0.110
242	0.140
248	0.160
261	0.160
273	0.110
283	0.070
293	0.000
298	-0.030
323	-0.150
334	-0.250
348	-0.380
359	-0.510
373	-0.640
386	-0.850
397	-0.980
410	-1.180
423	-1.340
433	-1.560
442	-1.760
448	-1.890
457	-2.110
CURVE 35*	
227	-1.340
248	-1.070
260	-0.900
273	-0.730
280	-0.550
286	-0.380
290	-0.230
291	-0.500
293	0.000
298	0.140
307	0.330
323	0.620
335	0.950
348	1.250
358	1.530
373	1.850
385	2.230
398	2.570
409	2.940
423	3.270
430	3.640
448	4.200
457	4.630
CURVE 36	
77	-1.030
300	0.047*
CURVE 37	
293	0.000*
300	0.054*
325	0.438*
350	0.745*

* Not shown in figure.

DATA TABLE 407. THERMAL LINEAR EXPANSION OF POLY(TETRAFLUOROETHYLENE) (continued)

T	$\Delta L/L_0$
CURVE 37 (cont.)	
375	1.110*
400	1.407*
425	1.761*
450	2.092
475	2.411
480	2.461
CURVE 38	
220	-0.825
225	-0.779*
242	-0.639
250	-0.586*
275	-0.282*
285	-0.165*
291	-0.064*
293	0.000*
300	0.175*
301	0.333
305	0.461
309	0.521
325	0.636*
350	0.833*
375	1.045*
400	1.257*
425	1.523*
450	1.801*
475	2.127
500	2.436
525	2.749
550	3.017
575	3.281
593	3.436
CURVE 39	
174	-1.147*
200	-0.985
216	-0.867
225	-0.778*
237	-0.652
250	-0.527*
262	-0.368*
275	-0.199*
286	-0.079
293	0.000
300	0.042*
311	0.142
325	0.256*
336	0.402
350	0.563
362	0.757
375	1.015*
400	1.587*
425	2.116
450	2.600
475	3.228
CURVE 40*	
0	-1.416
25	-1.373
50	-1.304
75	-1.221
100	-1.113
125	-0.999
150	-0.868
175	-0.706
180	-0.678
CURVE 41	
77	-1.463
3[illegible]	0.047*

* Not shown in figure.

DATA TABLE 407. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(TETRAFLUOROETHYLENE)

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

CURVE 13‡

T	α
173	78.0
183	86.6
193	94.2
203	89.6
213	91.2
223	93.6
233	97.2
243	97.9
253	100.5
263	102.4
273	106.0
283	130.9
293	216.2*
303	95.5*
313	91.6*
323	89.9*
333	100.6*
343	101.3*
353	130.5*
363	164.8*
373	228.9*
383	264.8*
393	250.2*
403	269.9*
413	241.4*
423	223.9*
433	203.1*
443	202.6*
453	190.7*
463	189.7*
473	189.7*

CURVE 22

T	α
90	38.4
99	39.7
109	41.2
120	43.1
126	44.4
132	45.9
138	47.9
143	50.0
148	52.0
154	54.9
160	58.5
162	60.8

CURVE 22 (cont.)

T	α
168	64.7
173	68.4
179	71.7
184	74.5
190	76.7
195	78.4
200	79.4
206	81.2
216	83.2
225	85.3
240	89.2
255	93.2
265	95.9
272	97.7
276	99.5
280	103.6
283	107.1
289	122.1
293	135.5
309	135.5*
314	116.6*
315	113.3*
318	111.5*
320	110.3*
332	108.8*

CURVE 23

T	α
98	38*
123	48
148	59
173	72
198	86
223	98
238	104
248	106
260	107
266	111
273	115
277	122
281	130*
284	140
286	156
290	185
293	523*
297	123

CURVE 23 (cont.)

T	α
300	173*
302	180*
303	176*
304	143*
305	126*
309	120*
323	119*
337	120*
348	123*
360	127*
373	133*
387	141*
398	148*
410	156*
423	165*
435	177*
448	188*
461	203*
473	215*
482	228*
493	243*
498	250*
506	265*
513	276*
523	293*
529	312*
535	330*
540	347*
548	376*
551	392*
554	409*
558	431*
560	448*
562	464*
564	486*
567	515*
571	566*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 408. THERMAL LINEAR EXPANSION OF POLY(N-HEXYL METHACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	543	Haldon, R.A. and Simha, R.	1968	V	108-261	PnHMA	Specimen 0.25 in. diameter, 1.0 in. long; obtained from Dr. D.L. Glusker of Rohm and Haas Co.; ends of cylinder filed flat, stored in vacuum.
2*	543	Haldon, R.A. and Simha, R.	1968	L	18-112	PnHMA	This curve is here reported using the first given temperature (18 K) as reference temperature at which $\Delta L/L_0 = 0$.

*No figure given.

DATA TABLE 408. THERMAL LINEAR EXPANSION OF POLY(N-HEXYL METHACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 2*,†,‡		CURVE 2 (cont.)*,†,‡	
108	-2.440	173	-1.883	226	-1.214	18	0.000	84	0.165
113	-2.403	178	-1.832	229	-1.166	25	0.006	87	0.181
118	-2.364	182	-1.790	232	-1.116	32	0.014	90	0.194
123	-2.325	185	-1.757	235	-1.066	37	0.023	92	0.210
127	-2.293	188	-1.724	238	-1.014	42	0.033	95	0.227
131	-2.261	192	-1.677	240	-0.979	47	0.043	97	0.238
137	-2.210	195	-1.640	243	-0.926	51	0.052	100	0.256
140	-2.185	198	-1.603	245	-0.890	54	0.061	102	0.270
144	-2.151	201	-1.564	248	-0.835	58	0.073	105	0.289
149	-2.108	205	-1.512	252	-0.761	61	0.082	108	0.204
153	-2.073	207	-1.485	254	-0.724	65	0.095	110	0.322
156	-2.048	210	-1.444	257	-0.669	68	0.105	112	0.337
159	-2.021	214	-1.390	259	-0.632	72	0.116		
163	-1.983	217	-1.348	261	-0.595	75	0.129		
167	-1.944	219	-1.319			79	0.142		
171	-1.904	223	-1.260			81	0.152		

DATA TABLE 408. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(N-HEXYL METHACRYLATE)

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 2*,‡		CURVE 2 (cont.)*,‡	
108	72.3	173	102.0	226	156.4	18	6.0	84	48.0
113	75.7	178	103.7	229	162.6	25	10.6	87	51.1
118	*77.6*	*182*	*107.0*	*232*	*167.7*	32	14.4	90	55.0
123	78.7	185	110.4	235	170.6	37	19.1	92	57.4
127	81.4	188	114.9	238	173.8	42	20.6	95	58.8
131	82.3	192	119.1	240	176.4	47	22.4	97	60.4
137	85.5	195	124.1	243	178.3	51	24.4	100	62.4
140	85.1	198	127.0	245	180.3	54	26.8	102	63.1
144	85.6	201	129.9	248	183.7	58	30.1	105	64.5
149	85.6	205	132.0	252	185.4	61	31.1	108	66.7
153	88.1	207	135.1	254	185.3	65	32.2	110	68.8
156	80.8	210	135.8	257	185.4	68	34.9	112	70.9
159	94.1	214	137.6	259	185.4	72	34.2		
163	97.4	217	142.8	261	186.2	75	37.3		
167	99.7	219	144.4			79	40.4		
171	100.4	223	150.7			81	43.0		

*No figure given.
†This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 409. THERMAL LINEAR EXPANSION OF POLY(CYCLOHEXYL METHACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	541	Acitelli, M.A., Gumby, W.L., and Naujokas, A.A.	1966	I	296-326		Sample suitably worked to form a tripod placed in furnace of instrument.

DATA TABLE 409. THERMAL LINEAR EXPANSION OF POLY(CYCLOHEXYL METHACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
296	0.019
305	0.076
326	0.320

*No figure given.

SPECIFICATION TABLE 410. THERMAL LINEAR EXPANSION OF POLY(2-HYDROXYETHYL METHACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	543	Haldon, R. A. and Simha, R.	1968	V	98-366	PHEMA	Specimen 0.25 in. diameter, 1.0 in. long; obtained from Dr. M.C. Shen of North American Aviation Science Center; ends of cylinder filed flat, stored in vacuum.

*No figure given.

DATA TABLE 410. THERMAL LINEAR EXPANSION OF POLY(2-HYDROXYETHYL METHACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡	
98	-0.72	163	-0.52	213	-0.35	256	-0.18	295	0.02	330	0.25
103	-0.70	167	-0.51	217	-0.33	259	-0.17	297	0.03	332	0.27
108	-0.69	171	-0.49	220	-0.32	261	-0.16	300	0.05	335	0.29
113	-0.67	174	-0.48	222	-0.31	264	-0.15	302	0.06	337	0.31
118	-0.66	177	-0.47	225	-0.30	267	-0.13	305	0.08	340	0.33
122	-0.65	181	-0.46	228	-0.29	270	-0.12	307	0.09	342	0.35
127	-0.65	184	-0.45	231	-0.28	273	-0.11	310	0.11	344	0.37
131	-0.62	188	-0.44	234	-0.27	275	-0.10	312	0.12	346	0.39
136	-0.60	191	-0.43	237	-0.26	277	-0.08	314	0.14	349	0.41
140	-0.59	194	-0.41	240	-0.25	280	-0.07	316	0.15	351	0.43
144	-0.58	197	-0.40	242	-0.24	282	-0.06	319	0.17	354	0.46
148	-0.57	201	-0.39	245	-0.23	285	-0.04	321	0.18	356	0.48
152	-0.55	204	-0.38	248	-0.21	287	-0.03	323	0.20	358	0.50
156	-0.54	207	-0.37	251	-0.20	290	-0.01	326	0.22	360	0.52
159	-0.53	210	-0.36	254	-0.19	293	0.00	328	0.24	362	0.54
										364	0.57
										366	0.60

DATA TABLE 410. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(2-HYDROXYETHYL METHACRYLATE)

[Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\ K^{-1}$]

T	α	T	α	T	α	T	α	T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡	
98	28.2	163	32.3	213	37.1	256	41.3	295	62.2	330	78.2
103	28.9	167	31.9	217	37.1	259	43.2	297	63.4	332	80.6
108	29.4	171	32.6	220	36.5	261	43.2	300	63.9	335	84.5
113	30.2	174	33.0	222	35.6	264	45.0	302	64.7	337	85.8
118	31.0	177	33.0	225	35.6	267	45.0	305	63.8	340	86.9
122	31.7	181	32.6	228	35.6	270	45.8	307	63.8	342	87.8
127	32.6	184	33.7	231	37.1	273	48.3	310	62.8	344	89.0
131	32.6	188	34.7	234	38.2	275	50.2	312	61.6	346	91.6
136	32.1	191	35.6	237	39.3	277	50.6	314	62.8	349	91.6
140	31.5	194	34.5	240	40.6	280	51.8	316	64.6	351	92.7
144	30.9	197	35.6	242	40.6	282	53.2	319	67.8	354	91.0
148	30.8	201	36.3	245	39.9	285	54.0	321	71.0	356	93.1
152	30.9	204	36.7	248	39.9	287	56.0	323	74.0	358	105.1
156	31.5	207	36.7	251	40.4	290	58.4	326	75.7	360	117.4
159	30.4	210	37.1	254	40.4	293	60.1	328	77.1	362	125.7
										364	127.9
										366	126.1

*No figure given.

‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 411. THERMAL LINEAR EXPANSION OF POLY(2-HYDROXYPROPYL METHACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	543	Haldon, R.A. and Simha, R.	1968	V	94-362	PHPMA	Specimen 0.25 in. diameter, 1.0 in long; obtained from Dr. M.C. Shen of North American Aviation Science Center; ends of cylinder filed flat, stored in vacuum.

*No figure given.

DATA TABLE 411. THERMAL LINEAR EXPANSION OF POLY(2-HYDROXYPROPYL METHACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡	
94	-0.78	164	-0.58	214	-0.40	257	-0.20	295	0.02	331	0.26
103	-0.76	167	-0.57	217	-0.38	260	-0.19	298	0.03	334	0.28
108	-0.75	171	-0.55	220	-0.37	262	-0.18	301	0.05	335	0.29
114	-0.73	175	-0.54	223	-0.36	265	-0.16	303	0.07	338	0.31
118	-0.72	178	-0.53	225	-0.35	267	-0.15	305	0.08	340	0.33
123	-0.70	181	-0.52	229	-0.34	270	-0.13	308	0.10	343	0.35
127	-0.69	185	-0.51	232	-0.32	273	-0.12	310	0.12	345	0.37
131	-0.68	188	-0.50	235	-0.31	275	-0.11	313	0.13	347	0.38
136	-0.66	192	-0.48	238	-0.29	278	-0.09	315	0.15	349	0.40
140	-0.65	195	-0.47	241	-0.28	280	-0.08	318	0.17	351	0.42
144	-0.64	198	-0.46	243	-0.27	283	-0.06	320	0.18	354	0.45
148	-0.63	201	-0.45	245	-0.26	286	-0.04	322	0.19	356	0.47
152	-0.61	205	-0.43	249	-0.24	288	-0.03	324	0.21	358	0.50
156	-0.60	207	-0.42	252	-0.23	290	-0.01	327	0.23	360	0.52
159	-0.59	211	-0.41	254	-0.22	293	0.00	329	0.25	362	0.54

DATA TABLE 411. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(2-HYDROXYPROPYL METHACRYLATE)

[Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\,K^{-1}$]

T	α	T	α	T	α	T	α	T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡	
94	23.9	164	33.0	214	41.0	257	51.5	295	63.9	331	70.5
103	26.2	167	33.6	217	40.6	260	52.3	298	64.8	334	71.8
108	28.8	171	33.0	220	41.2	262	53.5	301	64.5	335	73.3
114	30.9	175	33.5	223	40.6	265	53.3	303	65.8	338	76.3
118	30.4	178	33.5	225	41.7	267	53.3	305	67.1	340	76.5
123	29.7	181	33.9	229	41.7	270	53.9	308	67.8	343	77.2
127	30.8	185	34.4	232	43.2	273	54.6	310	67.9	345	79.1
131	30.8	188	35.2	235	44.5	275	56.1	313	68.9	347	82.9
136	30.0	192	36.7	238	44.5	278	56.4	315	69.1	349	89.3
140	29.7	195	37.1	241	45.6	280	58.0	318	69.3	351	96.7
144	30.0	198	37.1	243	46.3	283	61.1	320	69.3	354	112.2
148	30.4	201	38.6	245	46.5	286	62.4	322	70.2	356	118.8
152	29.9	205	39.5	249	49.1	288	64.8	324	70.2	358	127.8
156	32.0	207	40.0	252	49.3	290	65.2	327	70.4	360	118.6
159	32.0	211	40.4	254	50.6	293	65.0	329	70.8	362	118.0

*No figure given.
‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

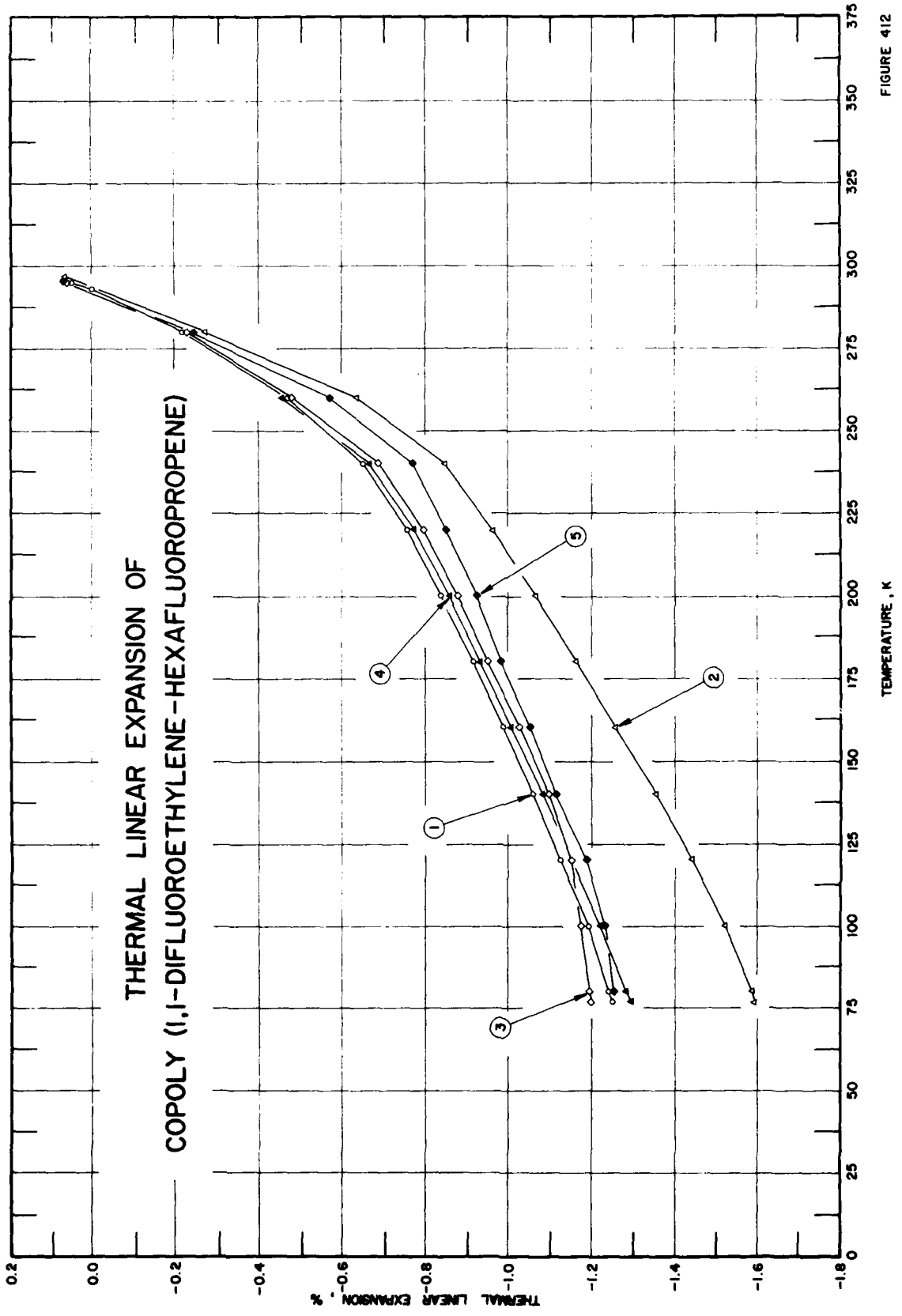

THERMAL LINEAR EXPANSION OF
COPOLY (1,1-DIFLUOROETHYLENE-HEXAFLUOROPROPENE)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
1
2
3
4
5

FIGURE 412

SPECIFICATION TABLE 412. THERMAL LINEAR EXPANSION OF COPOLY(1,1-DIFLUOROETHYLENE-HEXAFLUOROPROPENE)

Cur. No.	Ref. No.	Author(s)	Year	Method Use	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	538	Weitzel, D.H., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1963	L	77-295	I-8D	Viton A, from DuPont; cured 20 min at 411 K, post cured 16 hr at 477 K; zero-point correction of -0.050%.
2	538	Weitzel, D.H., et al.	1963	L	77-297	I-29F	Similar to the above specimen; cured 20 min at 427 K; zero-point correction of -0.067%.
3	538	Weitzel, D.H., et al.	1963	L	77-295	I-12A	Terpolymer with third monomer unidentified; Viton B from DuPont; cured 20 min at 427 K; post cured 16 hr at 477 K; zero-point correction of -0.060%.
4	538	Weitzel, D.H., et al.	1963	L	77-295	I-12B	Viton A-HV, from DuPont; cured 20 min at 427 K; post cured 16 hr at 477 K; zero-point correction of -0.045%.
5	538	Weitzel, D.H., et al.	1963	L	77-296	I-12C	Fluorel, from Minnesota Mining and Mfg; cured 20 min at 427 K; post cured 16 hr at 477 K; zero-point correction of -0.067%.

DATA TABLE 412. THERMAL LINEAR EXPANSION OF COPOLY(1,1-DIFLUOROETHYLENE-HEXAFLUOROPROPENE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
77	-1.251
80	-1.241
100	-1.192
120	-1.126
140	-1.060
160	-0.988
180	-0.918
200	-0.839
220	-0.757
240	-0.651
260	-0.470
280	-0.219
293	0.000
295	0.050
CURVE 2	
77	-1.594
80	-1.586
100	-1.521
120	-0.441
140	-1.354
CURVE 2 (cont.)	
160	-1.258
180	-1.163
200	-1.065
220	-0.964
240	-0.849
260	-0.638
280	-0.272
293	0.000*
297	0.067
CURVE 3	
77	-1.200
80	-1.196
100	-1.175
120	-1.151
140	-1.099
160	-1.028
180	-0.953
200	-0.878
220	-0.796
240	-0.687
CURVE 3 (cont.)	
260	-0.479
280	-0.227
293	0.000*
295	0.060
CURVE 4	
77	-1.296
80	-1.281
100	-1.221
120	-1.147*
140	-1.082
160	-1.006
180	-0.930
200	-0.859
220	-0.772
240	-0.665
260	-0.457
280	-0.216*
293	0.000*
295	0.045*
CURVE 5	
77	-1.256*
80	-1.254
100	-1.232
120	-1.187
140	-1.117
160	-1.051
180	-0.982
200	-0.923
220	-0.850
240	-0.770
260	-0.572
280	-0.243
293	0.000*
296	0.067

* Not shown in figure.

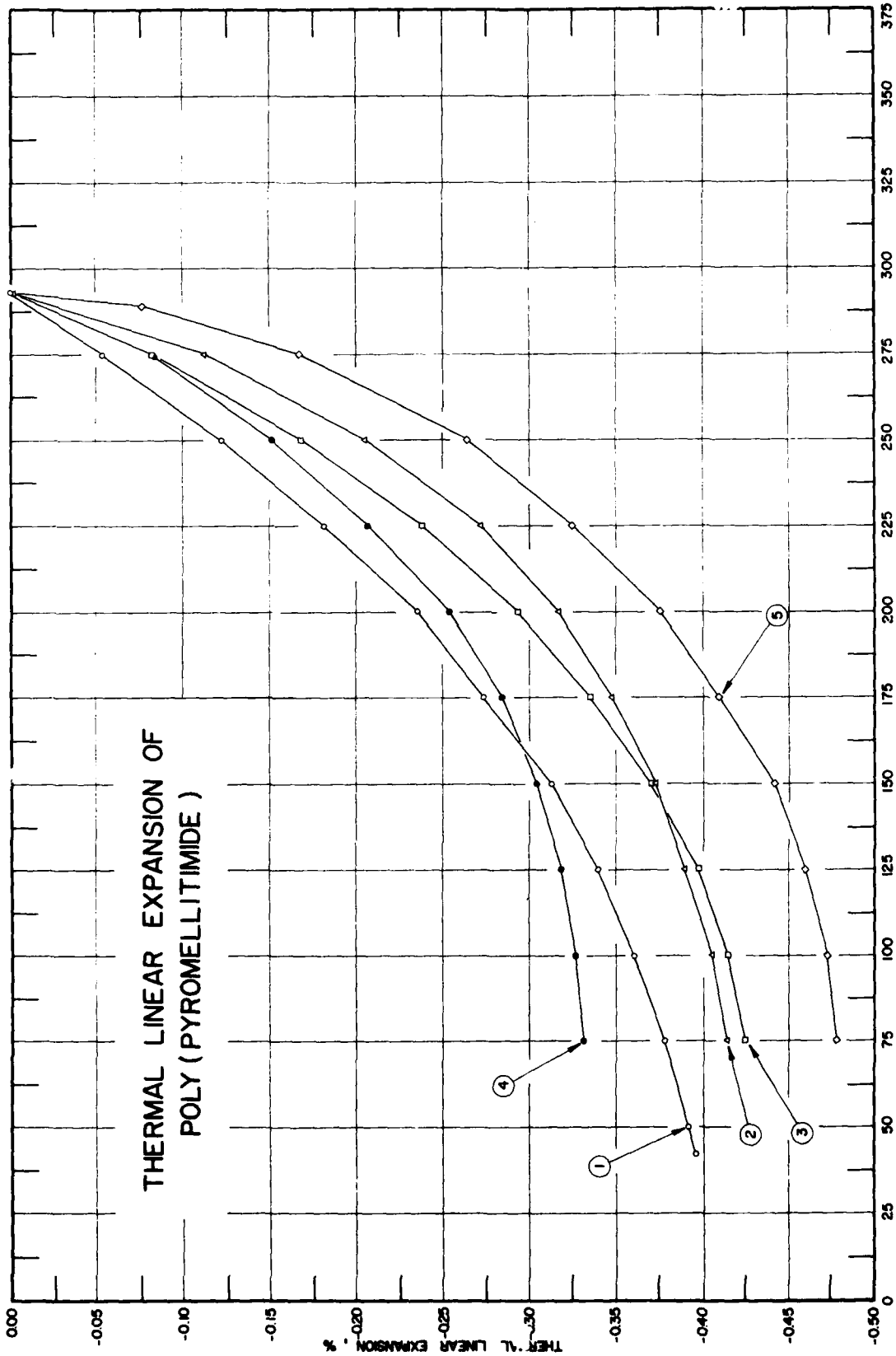

THERMAL LINEAR EXPANSION OF
POLY (PYROMELLITIMIDE)
THERMAL LINEAR EXPANSION, %
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
-0.40
-0.45
-0.50
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
TEMPERATURE, K
1
2
3
4
5

FIGURE 413

SPECIFICATION TABLE 413. THERMAL LINEAR EXPANSION OF POLY(PYROMELLITIMIDE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1032	Caren, R.P., Coston, R.M., Holmes, A.M.C., and Dubus, F.	1965		42-293	H-Film	Specimen of length 5.08 cm, diameter 0.635; rolled into tight cylinders; fused quartz tube and dial indicator test procedure used; three samples tested and quoted data scatter within 5%.
2	1048	Schramm, R.E., Clark, A.F., and Reed, R.P.	1973		75-293	H-Film	Two chemical' identical pots used; Lot A assumed to be typical; thickness of 0.005, 0.007, and 0.013 cm; ASTM D969-44 test procedure; linear differential transformer and an x-y recorder; Lot A, in long. direction; investigator, Hoggatt, J.T.; The Boeing Co., Contract No. EWA 69829, Document No. D2-23778-1 (1965).
3	1048	Schramm, R.E., et al.	1973		75-293	H-Film	Similar to the above specimen, except Lot A, in trans. direction.
4	1048	Schramm, R.E., et al.	1973		75-293	H-Film	Similar to the above specimen, except Lot B, in long. direction.
5	1048	Schramm, R.E., et al.	1973		75-293	H-Film	Similar to the above specimen, except Lot B, in trans. direction.
6*	1048	Schramm, R.E., et al.	1973		296,400		SP-1 ASTM D969 test procedure; zero-point correction of 0.075 determined by graphical extrapolation; investigator, Todd, N.W.; Machine Design 38, 81 (June 16, 1965).

DATA TABLE 413. THERMAL LINEAR EXPANSION OF POLY(PYROMELLITIMIDE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
42	-0.395
50	-0.391
75	-0.377
100	-0.360
125	-0.339
150	-0.312
175	-0.273
200	-0.235
225	-0.181
250	-0.122
275	-0.054
293	0.000
CURVE 2	
75	-0.413
100	-0.405
125	-0.389
150	-0.372
175	-0.347
200	-0.316
225	-0.271
250	-0.205
275	-0.112
293	0.000*
CURVE 3	
75	-0.424
100	-0.414
125	-0.397
150	-0.370
175	-0.335
200	-0.293
225	-0.238
250	-0.168
275	-0.082
293	0.000*
CURVE 4	
75	-0.331
100	-0.326
125	-0.318
150	-0.304
175	-0.284
200	-0.253
225	-0.206
250	-0.151
275	-0.082*
293	0.000*
CURVE 5	
75	-0.477
100	-0.472
125	-0.459
150	-0.441
175	-0.409
200	-0.375
225	-0.324
250	-0.264
275	-0.167
289	-0.076
293	0.000*
CURVE 6*	
296	0.075
400	2.675

* Not shown in figure.

SPECIFICATION TABLE 414. THERMAL LINEAR EXPANSION OF POLY(2-METHOXYETHYL METHACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	543	Haldon, R.A. and Simha, R.	1968	V	114-312	PMEMA	Specimen 0.25 in. diameter, 1.0 in. long; ends of cylinder filed flat, stored in vacuum.

*No figure given.

DATA TABLE 414. THERMAL LINEAR EXPANSION OF POLY(2-METHOXYETHYL METHACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡	
114	-1.310	160	-1.069	198	-0.833	232	-0.594	263	-0.342	291	-0.028
118	-1.288	164	-1.046	202	-0.808	235	-0.572	265	-0.320	293	0.000
123	-1.266	168	-1.026	205	-0.785	238	-0.553	268	-0.289	296	0.041
127	-1.243	171	-1.007	208	-0.767	241	-0.531	270	-0.266	298	0.078
132	-1.218	175	-0.983	211	-0.745	243	-0.513	273	-0.235	301	0.115
137	-1.195	178	-0.963	214	-0.725	246	-0.491	275	-0.208	303	0.150
140	-1.176	182	-0.938	217	-0.704	249	-0.467	278	-0.181	305	0.190
145	-1.153	186	-0.914	220	-0.682	252	-0.443	281	-0.147	308	0.227
148	-1.133	189	-0.895	223	-0.662	254	-0.419	283	-0.118	310	0.263
152	-1.113	192	-0.876	226	-0.636	257	-0.396	286	-0.089	312	0.302
156	-1.091	195	-0.854	229	-0.620	259	-0.372	288	-0.060		

DATA TABLE 414. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(2-METHOXYETHYL METHACRYLATE)

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α	T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡	
114	48.8	160	56.7	198	66.8	232	73.1	263	99.7	291	129.9
118	49.5	164	58.6	202	67.4	235	73.1	265	103.3	293	134.6
123	50.8	168	60.1	205	67.4	238	73.9	268	103.4	296	140.8
127	52.3	171	61.4	208	68.2	241	76.2	270	106.2	298	147.1
132	51.9	175	62.3	211	68.5	243	77.1	273	106.6	301	156.7
137	51.9	178	62.3	214	69.8	246	78.3	275	109.1	303	164.7
140	52.2	182	62.7	217	70.7	249	82.9	278	110.8	305	164.7
145	51.6	186	63.6	220	72.0	252	86.4	281	111.5	308	163.1
148	51.6	189	65.1	223	72.6	254	90.3	283	115.6	310	161.2
152	52.9	192	65.1	226	72.6	257	94.0	286	121.8	312	162.5
156	54.9	195	65.5	229	72.6	259	96.8	288	125.0		

*No figure given.
‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 415. THERMAL LINEAR EXPANSION OF POLY(METHYL ACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	543	Haldon, R.A. and Simha, R.	1968	V	109-303	PMA	Specimen 0.25 in. diameter, 1.0 in. long; obtained from Dr. D. L. Glusker of Rohm and Haas Co.; ends of cylinder filed flat, stored in vacuum.
2*	543	Haldon, R.A. and Simha, R.	1968	V	98-280	PMA	The above specimen; expansion measured on second run; zero-point correction is -0.100%.

*No figure given.

DATA TABLE 415. THERMAL LINEAR EXPANSION OF POLY(METHYL ACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 2*,‡		CURVE 2 (cont.)*,‡		CURVE 2 (cont.)*,‡	
109	-1.34	192	-0.86	251	-0.45	98	-1.42	175	-0.99	232	-0.60
114	-1.32	202	-0.80	254	-0.43	103	-1.40	178	-0.97	235	-0.58
118	-1.29	205	-0.78	262	-0.36	108	-1.37	181	-0.95	237	-0.56
123	-1.27	208	-0.76	265	-0.34	113	-1.35	181	-0.94	240	-0.54
127	-1.25	211	-0.74	268	-0.32	118	-1.32	185	-0.92	243	-0.51
132	-1.23	214	-0.72	270	-0.30	122	-1.36	188	-0.90	246	-0.49
136	-1.20	217	-0.70	273	-0.27	127	-1.27	195	-0.86	249	-0.47
140	-1.18	220	-0.68	275	-0.25	131	-1.25	198	-0.84	251	-0.45
144	-1.16	223	-0.66	278	-0.23	136	-1.22	201	-0.82	254	-0.42
148	-1.13	226	-0.64	281	-0.20	140	-1.20	205	-0.79	257	-0.40
152	-1.11	229	-0.62	284	-0.16	144	-1.18	208	-0.77	260	-0.38
156	-1.09	232	-0.60	286	-0.13	148	-1.15	211	-0.75	263	-0.35
160	-1.06	235	-0.57	289	-0.07	152	-1.12	214	-0.73	265	-0.33
164	-1.04	238	-0.56	293	0.000	156	-1.10	217	-0.71	267	-0.31
167	-1.02	240	-0.54	296	0.068	160	-1.08	220	-0.69	270	-0.29
171	-0.99	243	-0.51	298	0.109	164	-1.05	223	-0.67	273	-0.27
185	-0.91	245	-0.50	301	0.153	167	-1.03	226	-0.66	275	-0.25
188	-0.89	249	-0.47	303	0.199	171	-1.01	229	-0.62	278	-0.23
										280	-0.20

DATA TABLE 415. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(METHYL ACRYLATE)

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α	T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 2*,‡		CURVE 2 (cont.)*,‡		CURVE 2 (cont.)*,‡	
109	48.7	192	64.0	251	77.0	98	47.2	175	63.0	232	75.9
114	49.4	202	64.2	254	79.6	103	49.1	178	63.0	235	75.9
118	49.8	205	64.7	262	85.8	108	50.0	181	62.9	237	76.8
123	50.3	208	63.8	265	86.5	113	52.4	181	63.6	240	79.0
127	50.3	211	64.2	268	86.5	118	53.5	185	63.6	243	80.0
132	50.9	214	64.2	270	86.5	122	54.7	188	64.1	246	80.4
136	53.4	217	65.5	273	87.5	127	55.1	195	64.1	249	82.5
140	54.7	220	66.1	275	87.0	131	55.8	198	65.5	251	82.5
144	56.9	223	67.8	278	82.8	136	57.1	201	66.1	254	83.1
148	57.2	226	69.5	281	112.6	140	59.2	205	67.4	257	83.1
152	59.0	229	71.8	284	139.5	144	60.2	208	67.4	260	84.0
156	62.8	232	72.7	286	185.2	148	61.4	211	68.2	263	84.0
160	63.5	235	73.2	289	192.4	152	62.0	214	68.2	265	84.0
164	63.9	238	73.9	293	187.0	156	61.1	217	69.3	267	84.1
167	64.4	240	76.3	296	190.9	160	61.1	220	70.5	270	84.1
171	63.7	243	76.2	298	188.0	164	61.1	223	70.9	273	84.1
185	61.6	245	75.0	301	188.8	167	61.5	226	73.5	275	84.7
188	62.3	249	75.0	303	192.5	171	62.0	229	75.9	278	87.1
										280	82.4

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

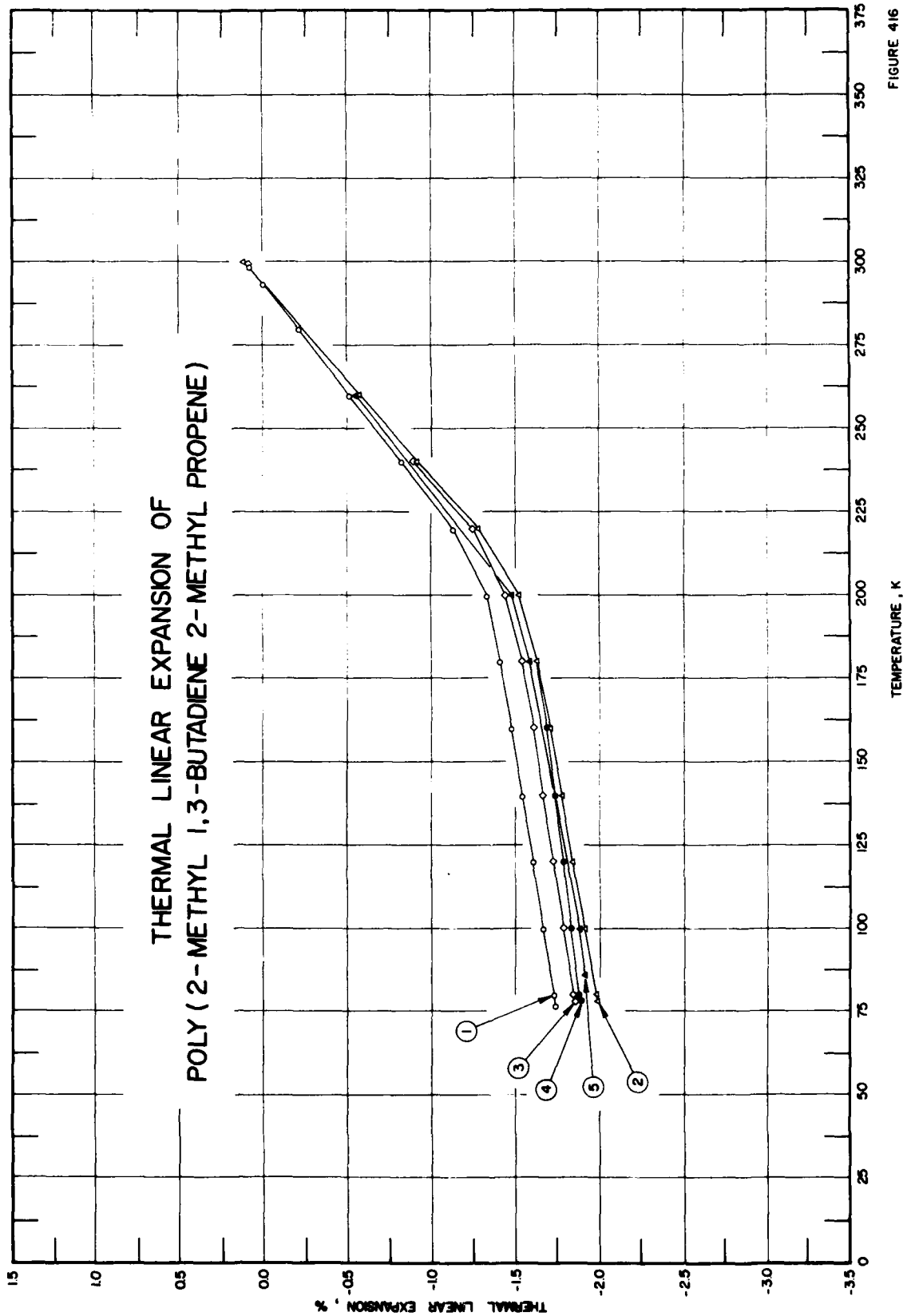

THERMAL LINEAR EXPANSION OF
POLY(2-METHYL 1,3-BUTADIENE 2-METHYL PROPENE)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
1
2
3
4
5

FIGURE 416

SPECIFICATION TABLE 416. THERMAL LINEAR EXPANSION OF POLY(2-METHYL 1,3-BUTADIENE 2-METHYL PROPENE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	538	Weitzel, D.N., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1963	L	77-298	III-18C	Butyl 035, cured 30 min at 427 K; Shore A hardness 70.
2	538	Weitzel, D.N., et al.	1963	L	78-300	III-18B	Butyl 325; cured 30 min at 427 K; Shore A hardness 75.
3	538	Weitzel, D.N., et al.	1963	L	78-299	III-18E	Butyl 325; resin cured 30 min at 427 K; Shore A hardness 75.
4	538	Weitzel, D.N., et al.	1963	L	78-300	III-18A	Hycar 2202, from B.F. Goodrich Chem. Co.; cured 30 min at 427 K; Shore A hardness 80.
5	538	Weitzel, D.N., et al.	1963	L	86-299	III-18B	HT-66, 1 percent chlorinated, from Enjay Chem. Co.; cured 30 min at 427 K; Shore A hardness 70.

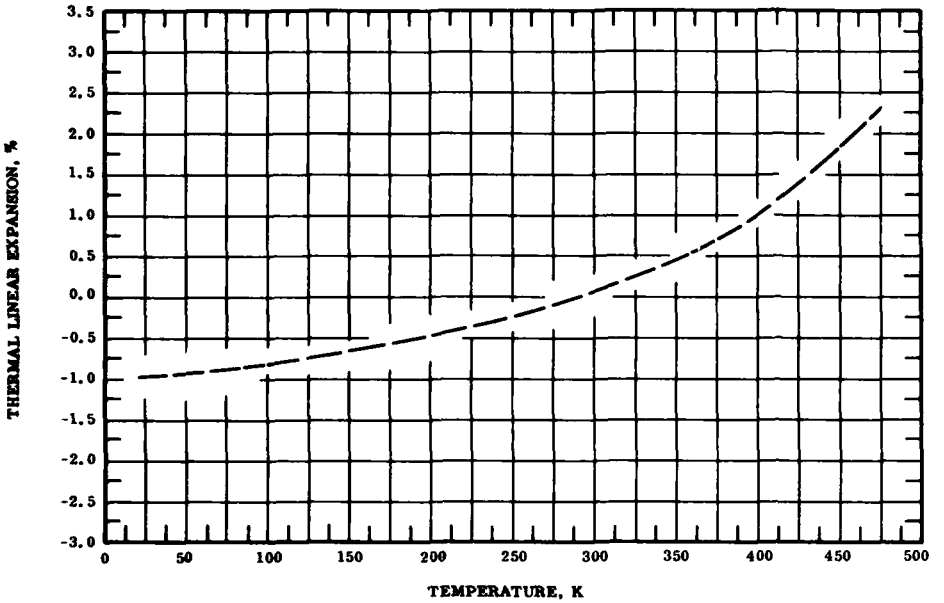
DATA TABLE 416. THERMAL LINEAR EXPANSION OF POLY(2-METHYL 1,3-BUTADIENE 2-METHYL PROPENE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1		CURVE 2		CURVE 3		CURVE 4		CURVE 5	
77	-1.746	78	-1.991	78	-1.851	78	-1.880	86	-1.913
80	-1.732	80	-1.980	80	-1.841	80	-1.875	100	-1.885
100	-1.671	100	-1.912	100	-1.781	100	-1.829	120	-1.840*
120	-1.608	120	-1.844	120	-1.722	120	-1.788	160	-1.680*
140	-1.544	140	-1.775	140	-1.664	140	-1.738	180	-1.585
160	-1.478	160	-1.705	160	-1.603	160	-1.688	200	-1.476
180	-1.415	180	-1.628	180	-1.540	180	-1.619*	220	-1.272*
200	-1.337	200	-1.521	200	-1.448	200	-1.531*	240	-0.903*
220	-1.133	220	-1.273	220	-1.242	220	-1.277*	260	-0.549
240	-0.821	240	-0.913	240	-0.895	240	-0.906*	280	-0.213*
260	-0.512	260	-0.572	260	-0.553*	260	-0.558*	293	0.000*
280	-0.209	280	-0.215*	280	-0.210*	280	-0.216*	299	0.109*
293	0.000	293	0.000*	293	0.000*	293	0.000*		
298	0.085	300	0.121	299	0.096	300	0.138*		

* Not shown in figure.

FIGURE AND TABLE NO. 417R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF POLY(METHYL METHACRYLATE)



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
20	-0.940	10
40	-0.916	11
60	-0.884	14
80	-0.844	23
100	-0.798	30
125	-0.728	32
150	-0.650	34
175	-0.561	37
200	-0.461	40
225	-0.351	44
250	-0.230	48
275	-0.099	56
293	0.000	61
350	0.398	78
390	0.860	168
400	1.003	170
420	1.317	172
440	1.675	172
460	2.071	173
475	2.398	174

REMARKS

The provisional values are based on the data for the annealed samples. Glass transition points are observed at 83 K (curve 4) and at 388 K (curve 1). These values are considered accurate to within ± 7% and are represented approximately by the following equations:

$$\Delta L/L_0 = -0.959 + 7.236 \times 10^{-4}\ T + 9.044 \times 10^{-6}\ T^2 - 1.067 \times 10^{-8}\ T^3 \qquad (20\text{–}293\ K)$$

$$\Delta L/L_0 = 2.46 - 1.970 \times 10^{-2}\ T + 3.443 \times 10^{-5}\ T^2 + 1.420 \times 10^{-8}\ T^3 \qquad (293\text{–}475\ K)$$

The tabulated values for the coefficient of thermal expansion are derived from the selected experimental data and are considered accurate to about ± 10%.

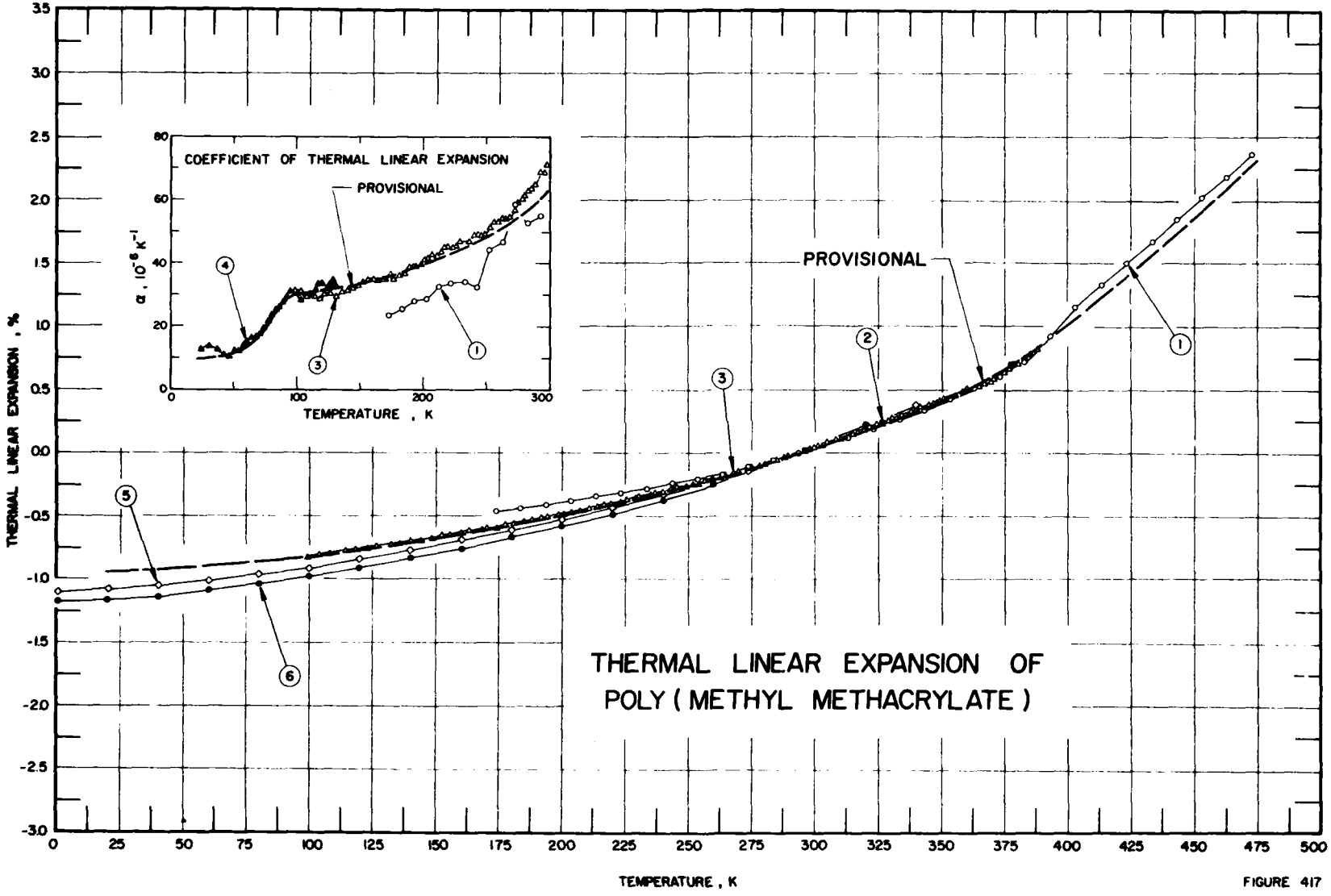

COEFFICIENT OF THERMAL LINEAR EXPANSION
PROVISIONAL
α, 10⁻⁶ K⁻¹
TEMPERATURE , K
PROVISIONAL
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
THERMAL LINEAR EXPANSION OF
POLY (METHYL METHACRYLATE)

FIGURE 417

SPECIFICATION TABLE 417. THERMAL LINEAR EXPANSION OF POLY(METHYL METHACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	171	Asay, J.R.	1968		173-473	Plexiglas	Specimen of density 1.19 g cm^{-3}, glass transition point Tg = 388 K.
2	541	Acitelli, M.A., Gumby, W.L., and Naujokas, A.A.	1966	I	297-378	Plexiglas	Sample suitably worked to form a tripod placed in furnace of instrument; specimen of specific gravity 1.154.
3	543	Haldon, R.A. and Simha, R.	1968	V	99-388	PMMA	Specimen 0.25 in. diameter, 1.0 in. long; ends of cylinder filed flat stored in vacuum; molded in compression mold at 438 K and 500 psi; annealed at about 293 K prior to measurement.
4*	544	Haldon, R.A. and Simha, R.	1968	L	25-130	PMMA	Glass transition point 83 K; this curve is here reported using the first given temperature (24.8 K) as reference temperature at which $\Delta L/L_0 = 0$.
5	548	Laquer, H.L. and Head, E.L.	1952	L	0-340		Rod specimen (.25 in. diameter; expansion measured parallel to the rod axis; zero-point correction of -0.125% determined by graphical interpolation.
6	548	Laquer, H.L. and Head, E.L.	1952	L	0-320		Similar to the above specimen except 1 in. diameter; expansion measured perpendicular to the rod axis; zero-point correction of -0.155% determined by graphical interpolation.

* Not shown in figure.

DATA TABLE 417. THERMAL LINEAR EXPANSION OF POLY(METHYL METHACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1‡	
173	-0.457
183	-0.432
193	-0.406
203	-0.377
213	-0.346
223	-0.313
233	-0.279
243	-0.246
253	-0.208
263	-0.163
273	-0.110
283	-0.054
293	0.000
303	0.059
313	0.123
323	0.193
333	0.267
343	0.345
353	0.429
363	0.516
373	0.609
383	0.725
393	0.927
403	1.154
413	1.336
423	1.512
433	1.683
443	1.854
453	2.026
463	2.199
473	2.371
CURVE 2	
297	0.029
327	0.248
378	0.705
CURVE 3‡	
99	-0.82
104	-0.80
108	-0.79
114	-0.77
118	-0.76
122	-0.75
127	-0.73
132	-0.72
136	-0.71
140	-0.69
144	-0.68
148	-0.67
152	-0.65
156	-0.64
160	-0.63
163	-0.61
168	-0.60
170	-0.59
174	-0.58
177	-0.56
181	-0.55
185	-0.54
188	-0.52
192	-0.51
194	-0.50
198	-0.49
201	-0.43
204	-0.46
207	-0.45
211	-0.43
214	-0.42
217	-0.41
219	-0.40
223	-0.38
226	-0.36
229	-0.35
237	-0.34
235	-0.32
237	-0.31
240	-0.30
243	-0.28
246	-0.27
249	-0.26
252	-0.24
254	-0.23
257	-0.21
260	-0.20
263	-0.18
265	-0.17
268	-0.15
270	-0.14
273	-0.13*
275	-0.11
278	-0.10
281	-0.08
283	-0.06*
286	-0.04
288	-0.03
290	-0.02
293	0.00*
296	0.02*
298	0.03
300	0.05
302	0.07
305	0.09
308	0.11
310	0.12
312	0.14*
315	0.16
317	0.17
319	0.19
322	0.21
324	0.23
327	0.25*
329	0.26
331	0.28
334	0.30
338	0.33
340	0.34
342	0.36
345	0.38
347	0.40
349	0.41
351	0.43
353	0.44*
356	0.46
358	0.48
360	0.49
362	0.51*
365	0.53
367	0.55
369	0.57
371	0.59
373	0.61*
375	0.64
377	0.67
379	0.69*
381	0.72
383	0.76
385	0.79
388	0.83
CURVE 4*, †, ‡	
25	0.000
32	0.009
38	0.017
43	0.023
47	0.027
51	0.033
55	0.037
59	0.042
61	0.046
65	0.053
69	0.058
72	0.064
75	0.069
78	0.076
81	0.082
84	0.090
87	0.097
90	0.105
93	0.113
95	0.122
99	0.132
100	0.138
103	0.145
105	0.151
111	0.168
115	0.182
117	0.188
120	0.199
125	0.213
127	0.220
129	0.226
130	0.233
CURVE 5	
0	-1.104
20	-1.084
40	-1.053
60	-1.010
80	-0.959
100	-0.902
120	-0.838
140	-0.767
160	-0.689
180	-0.605
200	-0.514
220	-0.416
240	-0.312
260	-0.202*
273.2	-0.125
280	-0.084*
300	0.045*
320	0.201*
340	0.389
CURVE 6	
0	-1.183
20	-1.170
40	-1.138
60	-1.093
80	-1.039
100	-0.978
120	-0.908
140	-0.833
160	-0.753
180	-0.667
200	-0.574
220	-0.474
240	-0.365
260	-0.245
CURVE 6 (cont.)	
273.2	-0.155*
280	-0.096*
300	0.052*
320	0.226

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 417. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(METHYL METHACRYLATE)

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1‡	
173	23.95
183	25.64
193	28.07
203	28.88
213	32.39
223	33.91
233	34.07
243	32.05
253	44.20
263	46.90
273	58.44
283	53.05
293	55.33
303	62.34*
313	66.98*
323	71.63*
333	76.27*
343	80.92*
353	85.57*
363	90.21*
373	94.86*
383	136.16*
393	268.99*
403	185.45*
413	178.75*
423	171.72*
433	171.01*
443	171.72*
453	172.42*
463	172.42*
473	172.41*
CURVE 3‡	
99	31.3
104	31.2
108	29.6
114	29.6
118	28.9
122	30.2
127	30.2
132	29.8
136	30.7
CURVE 3 (cont.)‡	
140	31.3
144	32.2
148	32.9
152	34.2
156	35.0
160	35.0
163	34.5
168	35.2
170	35.7
174	36.8
177	35.1
181	36.2
185	36.9
188	38.7
192	39.3
194	39.3
198	39.8
201	41.1
204	41.8
207	42.6
211	42.6
214	43.8
217	45.0
219	45.1
223	45.1
226	45.8
229	47.0
237	47.0
235	48.1*
237	47.6*
240	49.1
243	49.1
246	49.1
249	49.5
252	51.5*
254	53.0
257	53.4
260	53.4
263	54.5
265	54.5
268	55.0
270	56.9*
273	56.9
CURVE 3 (cont.)‡	
275	59.3
278	60.2
281	61.6
283	62.9
286	63.9
288	65.0
290	65.5*
293	68.9
296	68.9
298	71.4
300	71.4*
302	72.3*
305	73.7*
308	71.3*
310	73.0*
312	71.9*
315	71.9*
317	72.0*
319	74.4*
322	72.8*
324	75.4*
327	75.4*
329	75.4*
331	75.4*
334	75.4*
338	75.4*
340	73.4*
342	76.5*
345	74.6*
347	74.6*
349	74.6*
351	73.5*
353	75.8*
356	76.9*
358	77.6*
360	77.6*
362	78.4*
365	80.1*
367	84.7*
369	93.2*
371	105.5*
373	120.2*
375	128.7*
CURVE 3 (cont.)‡	
377	135.5*
379	145.8*
381	155.4*
383	164.1*
386	161.8*
388	161.2*
CURVE 4‡	
25	12.7
32	14.0
38	12.7
43	10.8
47	10.3
51	12.3
55	12.4
59	14.3
61	15.3
65	16.7
68	16.7
72	17.8
75	19.8
78	21.7
81	23.6
84	25.7
87	26.2
90	27.9
93	29.5
95	31.2
99	31.4*
100	30.2
103	28.2
105	28.5*
111	30.1
115	31.9
117	33.9
120	33.9
125	32.7
127	33.9
129	34.9
130	33.4

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 418. THERMAL LINEAR EXPANSION OF POLY(METHYL PENTENE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	544	Haldon, R.A. and Simha, R.	1968	L	19-118	P4MP1	Poly(4-methyl 1-pentene) specimen supplied by ICI Plastics Division; pressed to shape under 5000 psi; this curve is here reported using the first given temperature (19 K) as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 418. THERMAL LINEAR EXPANSION OF POLY(METHYL PENTENE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,†,‡		CURVE 1 (cont.)*,†,‡		CURVE 1 (cont.)*,†,‡		CURVE 1 (cont.)*,†,‡		CURVE 1 (cont.)*,†,‡	
19	0.000	51	0.148	71	0.282	90	0.417	105	0.556
25	0.018	55	0.171	75	0.307	92	0.441	108	0.579
32	0.044	58	0.195	78	0.332	96	0.470	111	0.605
38	0.069	62	0.219	81	0.352	98	0.487	113	0.625
43	0.097	65	0.242	84	0.375	100	0.508	115	0.647
47	0.123	68	0.261	87	0.395	103	0.531	118	0.668

DATA TABLE 418. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(METHYL PENTENE)

[Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\ K^{-1}$]

T	α	T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡	
19	23.1	71	70.0	105	90.0
25	32.0	75	70.4	108	91.2
32	42.8	78	71.2	111	90.0
38	50.3	81	72.5	113	91.1
43	57.3	84	74.4	115	90.2
47	61.1	87	77.7	118	89.5
51	62.0	90	81.9		
55	66.2	92	85.8		
58	67.6	96	87.6		
62	68.0	98	87.8		
65	68.0	100	87.8		
68	69.3	103	89.4		

*No figure given.
†This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 419. THERMAL LINEAR EXPANSION OF POLY(2-METHYL 5-VINYL PYRIDINE ACRYLONITRILE BUTADIENE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	538	Weitzel, D.H., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1963	L	76-296	VIII-28C	Specimen cured 45 min at 427 K; zero-point correction of -0.060%.

DATA TABLE 419. THERMAL LINEAR EXPANSION OF POLY(2-METHYL 5-VINYL PYRIDINE ACRYLONITRILE BUTADIENE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
76	-1.432
80	-1.415
100	-1.341
120	-1.275
140	-1.216
160	-1.146
180	-1.069
200	-0.991
220	-0.893
240	-0.767
260	-0.511
280	-0.206
293	0.000
296	0.060

*No figure given.

SPECIFICATION TABLE 420. THERMAL LINEAR EXPANSION OF POLYMETHYLENE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	559	Orwoll, R.A. and Flory, P.J.	1967	L	413-453		Marlex 50 polymethylene, tested as received from Phillips Petroleum Co.; this curve is here reported by using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
2*	559	Orwoll, R.A. and Flory, P.J.	1967	L	413-453		Marlex 6050 polymethylene, tested as received from Phillips Petroleum Co.; this curve is here reported by using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 420. THERMAL LINEAR EXPANSION OF POLYMETHYLENE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,†,‡		CURVE 2*,†,‡	
413	0.000	413	0.000
433	1.446	433	1.211
453	2.909	453	2.853

DATA TABLE 420. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLYMETHYLENE

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1*,‡	
413	720.0
433	726.0
453	737.0
CURVE 2*,‡	
413	693.0
433	718.0
453	724.0

*No figure given.
†This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

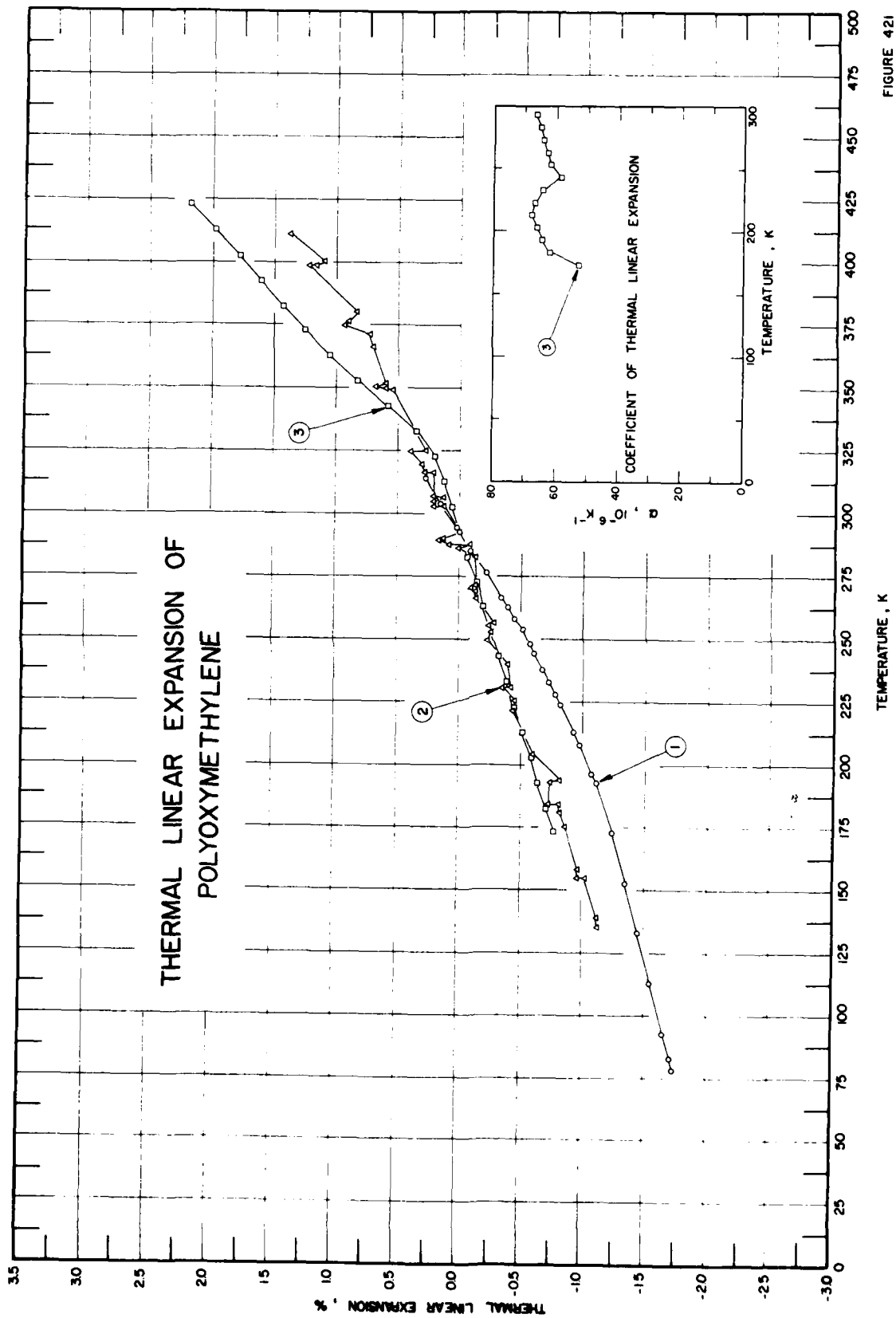

THERMAL LINEAR EXPANSION OF
POLYOXYMETHYLENE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K
1
2
3

FIGURE 421

SPECIFICATION TABLE421. THERMAL LINEAR EXPANSION OF POLYOXYMETHYLENE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	553	Mandelkern, L. and Stehling, F.C. Stehling, F.C.	1969		78-314		Low density specimen; second order transition temperature Tg at 188 K.
2	564	Aoki, Y., Chiba, A., and Kaneko Kaneko, M.	1969	X	136-412		Crystal specimen; (110) Bragg reflection used for expansion measurement; (110) spacing reported at 293 K is 2.235 Å.
3	171, 554	Asay, J.R., Urzendowski, R., and Guenther, A.H.	1968		173-423	Delrin Acetal DA-500	Highly crystalline form of formaldehyde (super polyoxymethylene); density 1.434 g cm^{-3}; m.p. 453 K; reported error ± 2.5%.

DATA TABLE 421. THERMAL LINEAR EXPANSION OF POLYOXYMETHYLENE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
78	-1.741
83	-1.704
113	-1.539
133	-1.440
153	-1.348
173	-1.236
193	-1.101
197	-1.064
208	-0.973
213	-0.912
224	-0.810
228	-0.768
233	-0.713
238	-0.667
244	-0.599
248	-0.557
254	-0.506
258	-0.448
263	-0.386
267	-0.339
277	-0.207
286	-0.097
293	0.000
295	0.027
304	0.161
314	0.288
CURVE 2	
136	-1.123
139	-1.123
141	-1.123*
155	-1.024
155	-0.966
158	-0.966
176	-0.854
182	-0.805
184	-0.805
184	-0.725
185	-0.805*
193	-0.738
194	-0.805
209	-0.590
222	-0.425
222	-0.403*
226	-0.442
231	-0.344
232	-0.412
232	-0.398*
240	-0.380
249	-0.228
250	-0.255*
253	-0.255
256	-0.228
257	-0.273
267	-0.134
267	-0.103*
269	-0.130
271	-0.094
271	-0.134*
272	-0.130
283	-0.130
282	-0.103*
287	0.000
287	0.018*
288	-0.076
288	-0.049*
288	0.085
290	0.170
291	0.143
293	0.000*
303	0.139
303	0.170
303	0.183*
303	0.215
304	0.174*
304	0.215*
305	0.183*
305	0.215
307	0.139
307	0.215
317	0.215
317	0.295
320	0.313
325	0.403
326	0.286
326	0.403*
329	0.403*
349	0.555
350	0.617
351	0.684
352	0.613
367	0.707
372	0.738
375	0.940
377	0.917
381	0.846
387	0.993*
399	1.172
399	1.123
401	1.114
412	1.387
CURVE 3‡	
173	-0.765
183	-0.708
193	-0.644
203	-0.579
213	-0.512
223	-0.444
233	-0.379
243	-0.317
253	-0.257*
263	-0.195
273	-0.131
283	-0.066
293	0.000 *
303	0.067
313	0.135
323	0.209
333	0.359
343	0.590
353	0.838
363	1.063
373	1.257
383	1.437
393	1.613
403	1.797
413	1.988
423	2.188

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 421. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLYOXYMETHYLENE

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3‡	
173	53.00
183	62.10
193	64.50
203	66.10
213	68.00
223	67.00
233	64.20
243	58.70
253	62.00
263	63.10
273	64.30
283	65.40
293	66.60
303	67.50*
313	67.60*
323	82.00*
333	216.60*
343	247.00*
353	247.90*
363	201.90*
373	185.60*
383	174.30*
393	178.20*
403	189.90*
413	191.50*
423	209.00*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 422. THERMAL LINEAR EXPANSION OF POLY(N-OCTYL METHACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	543	Haldon, R.A. and Simha, R.	1968	V	115-247	PnOMA	Specimen 0.25 in. diameter, 1.0 in. long; obtained from Dr. G. L. Glusker of Rohm and Haas Co.; ends of cylinder filed flat stored in vacuum.
2*	543	Haldon, R.A. and Simha, R.	1968	L	26-121	PnOMA	This curve is here reported using the first given temperature (26 K) as reference temperature at which $\Delta L/L_0 = 0$.

* No figure given.

DATA TABLE 422. THERMAL LINEAR EXPANSION OF POLY(N-OCTYL METHACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 2 (cont.)*,†,‡		CURVE 2 (cont.)*,†,‡	
115	-2.333	178	-1.788	229	-1.116	55	0.066	103	0.292
119	-2.303	181	-1.757	232	-1.066	59	0.078	106	0.310
124	-2.264	184	-1.724	235	-1.015	62	0.089	108	0.328
128	-2.233	188	-1.680	238	-0.963	65	0.100	111	0.346
132	-2.202	191	-1.645	241	-0.911	69	0.116	113	0.364
136	-2.169	194	-1.608	244	-0.859	72	0.127	116	0.384
140	-2.137	198	-1.558	247	-0.806	75	0.140	118	0.403
144	-2.103	202	-1.507			79	0.157	121	0.424
149	-2.060	205	-1.468	CURVE 2*,†,‡		81	0.168		
152	-2.033	208	-1.428			84	0.182		
156	-1.997	211	-1.387	26	0.000	87	0.198		
159	-1.970	214	-1.346	32	0.011	89	0.212		
164	-1.924	217	-1.303	38	0.022	93	0.229		
168	-1.886	220	-1.259	43	0.034	96	0.246		
171	-1.857	223	-1.213	47	0.045	98	0.262		
175	-1.818	226	-1.166	51	0.054	100	0.275		

DATA TABLE 422. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(N-OCTYL METHACRYLATE)

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α	T	α	T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 2 (cont.)*,‡		CURVE 2 (cont.)*,‡	
115	75.7	178	101.7	229	165.9	55	29.4	103	63.5
119	76.8	181	105.6	232	169.9	59	33.5	106	67.2
124	77.4	184	110.1	235	171.2	62	35.9	108	70.6
128	77.4	188	113.6	238	173.2	65	37.2	111	76.0
132	79.7	191	119.3	241	174.6	69	38.9	113	78.0
136	81.8	194	123.8	244	174.6	72	40.6	116	79.7
140	81.8	198	126.7	247	175.9	75	42.4	118	80.8
144	85.5	202	129.6			79	46.3	121	80.8
149	88.0	205	131.4	CURVE 2*,‡		81	48.7		
152	90.2	208	134.5			84	52.5		
156	90.6	211	136.5	26	14.3	87	54.4		
159	91.2	214	139.5	32	19.5	89	55.6		
164	93.3	217	143.9	38	20.7	93	56.8		
168	94.1	220	149.8	43	23.7	96	58.9		
171	97.1	223	156.3	47	26.1	98	58.9		
175	99.8	226	161.9	51	17.4	100	60.9		

* No figure given.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 423. THERMAL LINEAR EXPANSION OF POLY(N-PROPYL METHACRYLATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	543	Haldon, R.A. and Simha, R.	1968	V	98-324	PnPMA	Specimen 0.25 in. diameter, 1.0 in. long; ends of cylinder filed flat, stored in vacuum; molded in compression mold at 438 K and 500 psi; annealed at about 293 K prior to measurement; highly cross-linked; obtained from Dr. M.C. Shen of North American Aviation Science Center.
2*	544	Haldon, R.A. and Simha, R.	1968	L	25-116	PnPMA	Glass transition temperature at 84 K; this curve is here reported using the first given temperature (25 K) as reference temperature at which $\Delta L/L_0 = 0$.

*No figure given.

DATA TABLE 423. THERMAL LINEAR EXPANSION OF POLY(N-PROPYL METHACRYLATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 2*,†,‡		CURVE 2 (cont.)*,†,‡	
98	-1.60	173	-1.12	231	-0.67	280	-0.16	25	0.000	92	0.204
103	-1.58	177	-1.10	234	-0.65	282	-0.14	32	0.005	96	0.225
108	-1.55	181	-1.07	237	-0.62	285	-0.10	37	0.010	98	0.238
112	-1.52	184	-1.05	239	-0.60	287	-0.07	43	0.019	101	0.252
118	-1.49	188	-1.02	242	-0.57	289	-0.05	47	0.029	103	0.268
122	-1.46	190	-1.00	245	-0.54	292	-0.005	51	0.040	108	0.300
126	-1.43	194	-0.97	248	-0.52	295	0.03	55	0.050	111	0.314
131	-1.40	198	-0.95	251	-0.49	298	0.06	58	0.061	116	0.348
136	-1.38	201	-0.92	254	-0.46	300	0.10	61	0.072		
140	-1.35	204	-0.89	256	-0.43	303	0.15	66	0.087		
144	-1.32	207	-0.87	259	-0.40	307	0.21	68	0.096		
148	-1.30	210	-0.84	262	-0.37	309	0.25	72	0.108		
151	-1.27	213	-0.82	265	-0.34	311	0.29	75	0.119		
156	-1.24	216	-0.79	267	-0.31	314	0.34	78	0.132		
159	-1.22	220	-0.77	270	-0.28	316	0.38	81	0.146		
163	-1.20	223	-0.74	273	-0.24	319	0.43	85	0.162		
166	-1.17	225	-0.72	275	-0.22	321	0.47	87	0.173		
170	-1.15	228	-0.70	278	-0.19	324	0.52	89	0.186		

DATA TABLE 423. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLY(N-PROPYL METHACRYLATE)

[Temperature, T, K; Coefficient of Expansion, α, $10^{-6}\ K^{-1}$]

T	α	T	α	T	α	T	α	T	α	T	α
CURVE 1*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 1 (cont.)*,‡		CURVE 2 (cont.)*,‡	
98	53.8	170	66.7	225	82.5	273	112.1	316	190.0	68	34.6
103	55.1	173	68.4	228	85.3	275	113.6	319	191.4	72	35.8
108	57.3	177	69.1	231	88.5	278	115.0	321	188.7	75	38.1
112	58.4	181	70.1	234	90.8	280	119.2	324	185.0	78	40.4
118	61.7	184	74.0	237	93.0	282	123.5			81	44.6
122	62.8	188	75.6	239	94.1	285	127.6	CURVE 2*,‡		85	49.4
126	63.9	190	76.8	242	95.0	287	130.7			87	53.0
131	63.9	194	79.8	245	96.8	289	133.1	25	4.4	89	55.4
136	63.9	198	79.8	248	97.7	292	136.1	32	9.4	92	56.6
140	65.1	201	79.8	251	99.1	295	136.9	37	14.2	96	58.2
144	65.8	204	79.8	254	102.5	298	136.9	43	20.0	98	59.2
148	66.4	207	80.7	256	103.5	300	136.9	47	24.6	101	60.8
151	68.1	210	81.5	259	108.3	303	149.9	51	26.4	103	62.1
156	68.0	213	79.3	262	111.8	307	168.4	55	30.9	108	63.0
159	66.9	216	80.1	265	115.9	309	184.3	58	33.0	111	63.9
163	66.9	220	80.1	267	113.3	311	187.7	61	33.6	116	64.9
166	67.9	223	80.1	270	112.1	314	189.1	66	34.3		

* No figure given.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 424. THERMAL LINEAR EXPANSION OF POLYPROPYLENE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	550	Zakim, J.L., Simha, R., and Hershey, H.C.	1966	V	90-293	Sample D	Specimen prepared by Dr. E. G. Kontos of Naugatuclo Chemical Co.
2*	550	Zakim, J.L., et al.	1966	V	90-293	Sample D	The above specimen; second test.

* No figure given.

DATA TABLE 424. THERMAL L. AR EXPANSION OF POLYPROPYLENE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*,‡	
90	-2.289
96	-2.261
101	-2.234
106	-2.205
111	-2.179
116	-2.151
120	-2.124
124	-2.101
129	-2.073
133	-2.051
137	-2.028
141	-2.002
146	-1.973
149	-1.955
153	-1.928
157	-1.902
161	-1.872
165	-1.846
168	-1.828
172	-1.798
176	-1.771
179	-1.752
183	-1.724
185	-1.705
189	-1.680
193	-1.654
195	-1.633
199	-1.610
202	-1.589
205	-1.565
209	-1.540
211	-1.519
214	-1.498
218	-1.475
221	-1.452
224	-1.429
227	-1.407
230	-1.384
232	-1.362
235	-1.340
238	-1.320
240	-1.298
243	-1.273
246	-1.248
249	-1.225
252	-1.196
254	-1.054
258	-0.714
259	-0.617
260	-0.604
263	-0.561
266	-0.517
268	-0.480
271	-0.425
273	-0.377
275	-0.333
278	-0.279
281	-0.235
283	-0.183
286	-0.137
288	-0.089
291	-0.033
293	0.000
CURVE 2*,‡	
90	-1.884
96	-1.855
101	-1.829
106	-1.800
111	-1.773
116	-1.745
121	-1.716
125	-1.693
129	-1.666
133	-1.639
137	-1.613
141	-1.589
146	-1.555
149	-1.530
153	-1.504
157	-1.475
161	-1.449
165	-1.423
168	-1.403
172	-1.374
176	-1.348
179	-1.324
183	-1.298
186	-1.277
189	-1.254
193	-1.224
196	-1.203
199	-1.177
202	-1.154
206	-1.127
208	-1.105
212	-1.082
214	-1.059
217	-1.038
221	-1.008
223	-0.989
227	-0.963
230	-0.938
233	-0.913
235	-0.890
238	-0.868
241	-0.842
244	-0.817
246	-0.795
249	-0.768
250	-0.759
255	-0.707
258	-0.665
260	-0.640
263	-0.595
265	-0.552
268	-0.499
272	-0.437
273	-0.402
276	-0.354
279	-0.293
281	-0.243
284	-0.186
287	-0.123
289	-0.083
292	-0.023
293	0.000

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 424. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLYPROPYLENE

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 1*,‡	
90	52.6
96	53.9
101	54.4
106	55.6
111	56.5
116	57.4
120	57.1
124	57.8
129	58.2
133	58.6
137	60.0
141	61.1
146	62.0
149	63.4
153	64.9
157	66.5
161	67.3
165	67.7
168	68.2
172	68.7
176	69.7
179	70.1
183	70.6
185	71.2
189	71.3
193	71.3
195	71.7
199	71.2
202	70.7
205	70.7
209	71.0
211	71.4
214	72.5
218	73.6
221	75.2
224	75.9
227	76.6
230	77.4
232	78.3
235	79.5
238	80.4
240	82.3
243	84.6
246	87.8
249	92.3
252	96.4
252	98.0
254	103.5
258	109.2
259	124.2
260	146.1
263	164.4
266	172.9
268	180.6
271	187.6
273	191.1
275	193.0
278	193.3
281	192.8
283	192.2
286	192.0
288	191.9
291	192.9
293	193.7
CURVE 2*,‡	
90	*52.6*
96	53.9
101	54.4
106	55.6
111	56.5
116	57.4
121	58.5
125	59.6
129	61.8
133	63.5
137	66.0
141	68.8
146	69.9
149	69.9
153	68.7
157	67.7
161	67.3
165	67.7
168	69.9
172	68.7
176	72.7
179	72.7
183	72.2
186	73.2
189	74.1
193	75.0
196	75.7
199	76.0
202	75.5
206	75.5
208	75.5
212	75.7
214	77.1
217	78.5
221	79.1
223	80.7
227	81.4
230	83.2
233	83.8
235	84.4
238	85.3
241	87.3
244	89.3
246	91.8
249	94.4
250	*102.0*
255	111.5
258	128.8
258	140.8
260	146.1
260	156.7
263	164.4
265	179.7
268	189.4
272	195.4
273	198.0
276	202.2
279	206.0
281	209.1
284	211.2
287	211.2
289	208.2
292	206.3
293	205.5

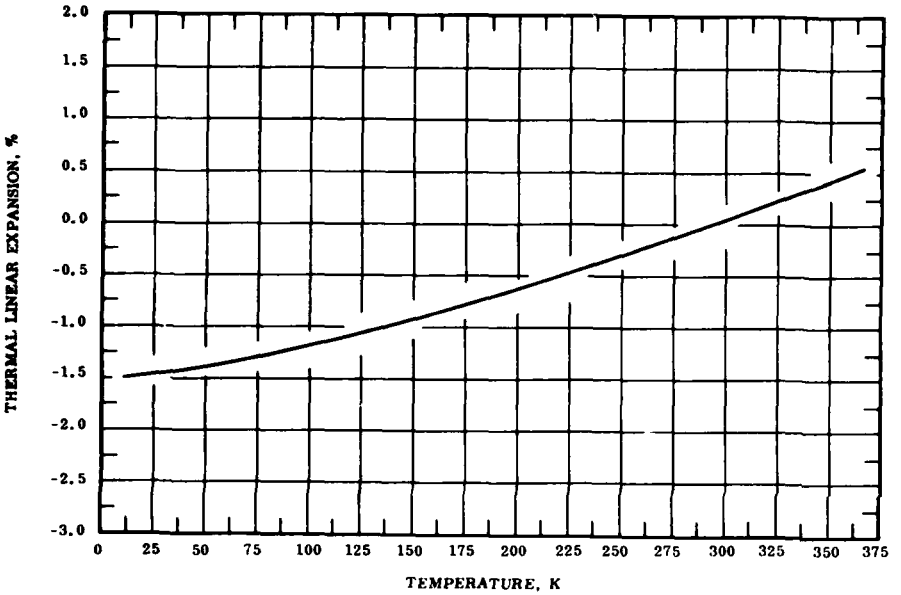
CURVE 1 (cont.)*,‡

CURVE 2 (cont.)*,‡

* No figure given.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 425R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF POLYSTYRENE



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
10	-1.516	19
20	-1.495	23
30	-1.470	26
40	-1.442	29
50	-1.411	33
60	-1.377	36
70	-1.340	39
80	-1.300	41
90	-1.257	44
100	-1.212	47
120	-1.114	51
140	-0.980	56
160	-0.892	59
180	-0.750	62
200	-0.643	65
220	-0.510	67
240	-0.374	69
260	-0.234	70
280	-0.093	71
293	0.000	71
300	0.050	71
325	0.228	71
370	0.575	71

REMARKS

The recommended values are considered accurate to within ± 5% and are represented approximately by the following equation:

$$\Delta L/L_0 = -1.533 + 1.551 \times 10^{-3} T + 1.865 \times 10^{-5} T^2 - 2.078 \times 10^{-8} T^3$$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equation and are considered accurate to about ± 10%.

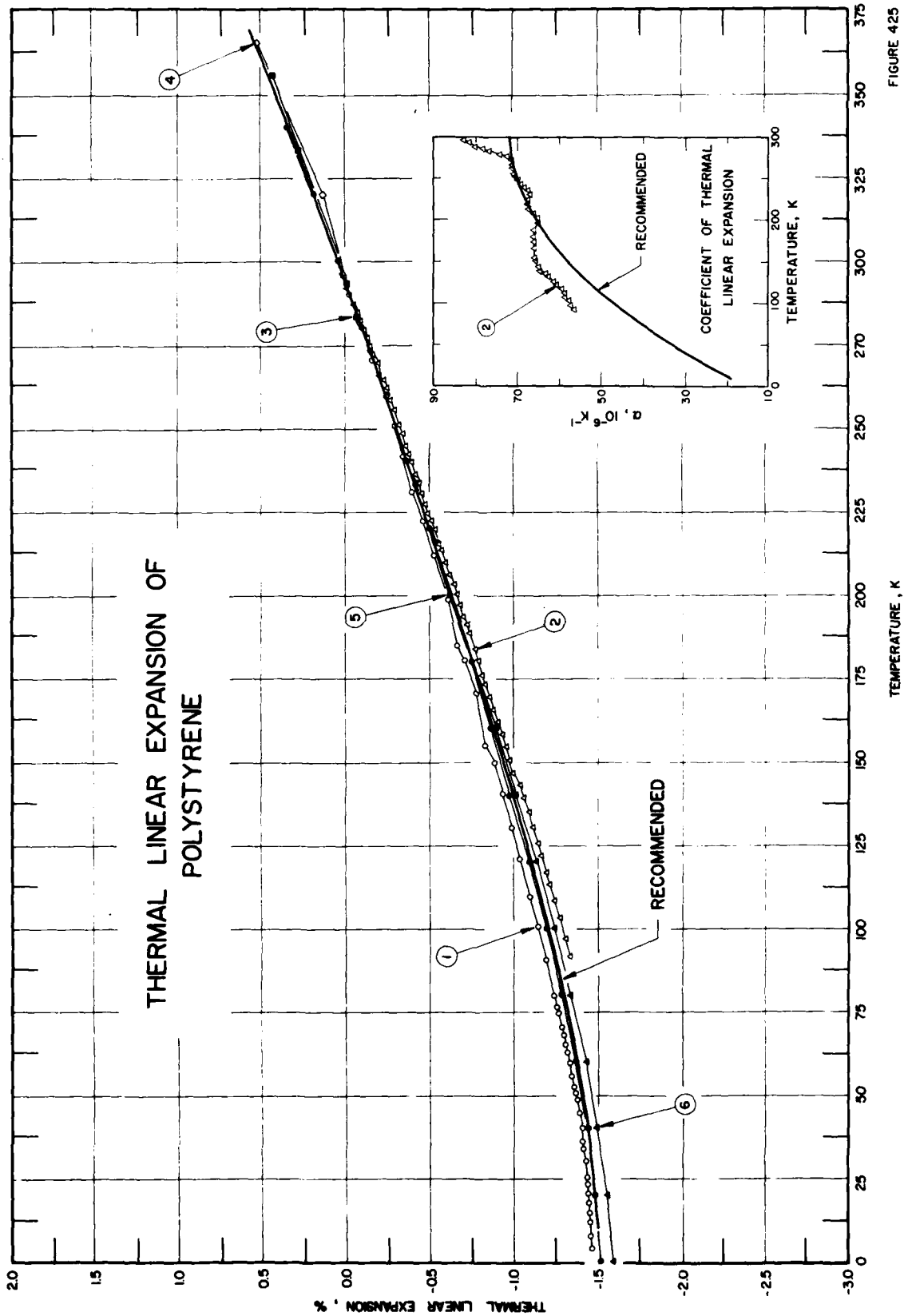

THERMAL LINEAR EXPANSION OF POLYSTYRENE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE, K
RECOMMENDED
1
2
3
4
5
6

FIGURE 425

SPECIFICATION TABLE 425. THERMAL LINEAR EXPANSION OF POLYSTYRENE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	549	Saba, R.G.	1967	E	4-290		Specimen received as polymer; twice purified by freeze-drying, then allowing solvent to sublime; specimen used as dielectric in capacitor and expansion measured by observing change in capacitance.
2	550	Zakin, J.L., Simha, R., and Hershey, H.C.	1966	V	92-294		Specimen prepared by National Bureau of Standards.
3	540	Hagenbuck, L.M.	1950	L	216-356		No details given; zero-point correction of -0.387%.
4	541	Acitelli, M.A., Gumby, W.L., and Naujokas, A.A.	1966	I	296-366		Sample suitably worked to form a tripod placed in furnace of instrument; vicat softening point 376 K.
5	548	Laquer, H.L. and Head, E.L.	1952	L	0-340		Rod specimen 0.25 in. diameter; a stock item probably from American Phenolic Corporation, grade 912 A; expansion measured parallel to rod direction; reported error ±1%; zero-point correction of -0.142% determined by graphical interpolation.
6	548	Laquer, H.L. and Head, E.L.	1952	L	0-300		Similar to the above specimen; 1 in. diameter; expansion measured perpendicular to rod direction; reported error ±1%; zero-point correction of -0.142% determined by graphical interpolation.

DATA TABLE 425. THERMAL LINEAR EXPANSION OF POLYSTYRENE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
4.2	-1.466
5.7	-1.463*
7.5	-1.460
9.1	-1.456*
9.5	-1.456
12.6	-1.452*
14.8	-1.450
16.9	-1.449*
17.8	-1.448
18.8	-1.447*
20.1	-1.446
21.6	-1.443*
23.6	-1.440
25.1	-1.437
27.4	-1.433*
30.2	-1.427
32.2	-1.421*
33.9	-1.417
35.3	-1.414*
36.5	-1.411
38.2	-1.407*
40.0	-1.412
42.0	-1.394*
44.8	-1.385
46.4	-1.379*
48.2	-1.373
50.4	-1.364
52.3	-1.356
54.8	-1.346*
56.4	-1.340
58.1	-1.333*
59.7	-1.326
61.2	-1.320*
62.6	-1.314
64.0	-1.308*
65.3	-1.304
66.6	-1.297*
67.8	-1.292
69.2	-1.285*
70.6	-1.280
72.6	-1.270*
74.1	-1.263
75.4	-1.257*
76.8	-1.251
78.3	-1.244*

T	$\Delta L/L_0$
CURVE 1 (cont.)	
79.9	-1.237
90.3	-1.188
100.2	-1.139
109.6	-1.091
121.7	-1.028
130.3	-0.982
140.0	-0.930
149.6	-0.878
159.6	-0.822
170.3	-0.762
180.0	-0.706
189.5	-0.651
198.3	-0.600
212.1	-0.517
222.0	-0.457
231.8	-0.398
241.9	-0.337
251.6	-0.276
259.4	-0.226
270.7	-0.150
280.1	-0.087
290.2	-0.019
CURVE 2‡	
92	-1.333
97	-1.305
103	-1.271
108	-1.242
113	-1.213
117	-1.190
122	-1.162
126	-1.137
131	-1.104
135	-1.080
139	-1.057
143	-1.031
147	-0.999
151	-0.974
154	-0.954
158	-0.928
162	-0.900
166	-0.874
169	-0.856
173	-0.828

T	$\Delta L/L_0$
CURVE 2 (cont.)‡	
176	-0.809
180	-0.782
183	-0.765
188	-0.734
191	-0.714
193	-0.699
197	-0.673
200	-0.651
203	-0.632
206	-0.613
209	-0.591
213	-0.570
215	-0.550
219	-0.529
222	-0.508
224	-0.489
227	-0.470
230	-0.450
233	-0.429
236	-0.410
239	-0.390
242	-0.372
244	-0.356
248	-0.332
251	-0.310
255	-0.280
258	-0.257
262	-0.233
264	-0.216
266	-0.198
269	-0.181
272	-0.159
274	-0.144
277	-0.124
279	-0.108
282	-0.089
284	-0.069
287	-0.049
289	-0.029*
292	-0.008
295	0.012
CURVE 3	
216	-0.547

T	$\Delta L/L_0$
CURVE 3 (cont.)	
233	-0.424
239	-0.387*
283	-0.067
293	0.000
333	0.289
356	0.446
CURVE 4	
296	0.016
320	0.148
366	0.547
CURVE 5	
0	-1.516
20	-1.489
40	-1.434
60	-1.364
80	-1.281
100	-1.187
120	-1.084
140	-0.974
160	-0.858
180	-0.738
200	-0.616
220	-0.492
240	-0.364
260	-0.232
273.2	-0.142
280	-0.094*
300	0.050
320	0.199
340	0.353
CURVE 6	
0	-1.585
20	-1.558
40	-1.499
60	-1.425
80	-1.337
100	-1.237
120	-1.128
140	-1.013

T	$\Delta L/L_0$
CURVE 6 (cont.)	
160	-0.892
180	-0.767*
200	-0.639*
220	-0.508*
240	-0.373*
260	-0.235*
273.2	-0.142*
280	-0.094
300	0.050*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 425. COEFFICIENT OF THERMAL LINEAR EXPANSION OF POLYSTYRENE

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α	T	α
CURVE 2‡		CURVE 2 (cont.)‡	
92	56.4	255	70.4
97	57.1	258	70.5*
103	57.9	262	71.0
108	58.6	264	71.4*
113	58.7	266	71.1
117	59.5	269	71.1*
122	60.9	272	71.1
126	61.3	274	71.3*
131	62.4	277	72.2
135	63.1	279	74.1
139	64.6	282	76.9
143	64.9	284	78.5
147	65.2*	287	80.1
151	65.9	289	80.6*
154	66.0	292	81.7
158	66.0*	295	82.7
162	66.0*		
166	66.0		
169	66.0*		
173	66.0		
176	66.3*		
180	66.3		
183	66.3*		
188	66.3		
191	66.3*		
193	66.0*		
197	65.1		
200	65.1*		
203	65.2		
206	65.5*		
209	66.3		
213	67.4		
215	67.4*		
219	67.8		
222	67.8*		
224	67.8		
227	67.1*		
230	67.2		
233	67.2*		
236	67.6		
239	68.4		
242	69.1		
244	69.8*		
248	69.8		
251	70.1		

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 426. THERMAL LINEAR EXPANSION OF POLYURETHANE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	538	Weitzel, D.H., Robbins. R.F., Ludtke, P.R., and Ohori, Y.	1963	L	70-297	VII-28E	Genthane S, from General Tire and Rubber, cured 30 min at 427 K; glass transition temperature Tg 237 K; zero-point correction of -0.086%.
2*	538	Weitzel, D.H., et al.	1963	L	70-297	VII-21F	Adiprene C, from DuPont, cured 30 min at 427 K; glass transition temperature Tg 224 K; zero-point correction of -0.086%.

DATA TABLE 426. THERMAL LINEAR EXPANSION OF POLYURETHANE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*	
70	-2.201	70	-2.314
80	-2.160	80	-2.253
100	-2.051	100	-2.126
120	-1.952	120	-2.004
140	-1.847	140	-1.884
160	-1.728	160	-1.771
180	-1.600	180	-1.646
200	-1.468	200	-1.515
220	-1.319	220	-1.345
240	-1.098	240	-1.063
260	-0.733	260	-0.672
280	-0.298	280	-0.261
293	0.000	293	0.000
297	0.086	297	0.086

* No figure given.

SPECIFICATION TABLE 427. THERMAL LINEAR EXPANSION OF COPOLY(VINYL CHLORIDE - VINYL ACETATE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	548	Laquer, H. L. and Head, E. L.	1952	L	0-320	Vinylite VYDR Vinyl polymer	Copolymer consisting of 95.0 vinyl chloride, 5.0 vinyl acetate; made by Bakelite Corp.; molded into 1.5 in. long, 1 in. diameter cylinder under pressure 6500 psi and 423 K for 5 min; specimen cut parallel to cylinder; reported error ±3%.

DATA TABLE 427. THERMAL LINEAR EXPANSION OF COPOLY(VINYL CHLORIDE - VINYL ACETATE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
0	-1.331
20	-1.296
40	-1.257
60	-1.201
80	-1.133
100	-1.058
120	-0.977
140	-0.890
160	-0.797
180	-0.699
200	-0.596
220	-0.483
240	-0.362
260	-0.233
273	-0.144
280	-0.098
300	0.042
320	0.185

*No figure given.

SPECIFICATION TABLE 428. THERMAL LINEAR EXPANSION OF POLY(VINYL CYCLOHEXENE DIOXIDE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	541	Acitelli, M. A. and Gumby, W. L.	1966	I	295-332		Sample suitably worked to form a tripod placed in furnace of instrument.

DATA TABLE 428. THERMAL LINEAR EXPANSION OF POLY(VINYL CYCLOHEXENE DIOXIDE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
295	0.0104
308	0.078
332	0.250

*No figure given.

SPECIFICATION TABLE 429. THERMAL LINEAR EXPANSION OF POLY(VINYL TOLUENE)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	541	Acitelli, M.A., Gumby, W.L., and Naujokas, A.A.	1966	I	297-333		Sample suitably worked to form a tripod placed in furnace of instrument; specimen of specific gravity 1.154.

DATA TABLE 429. THERMAL LINEAR EXPANSION OF POLY(VINYL TOLUENE)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
297	0.025
313	0.128
333	0.364

*No figure given.

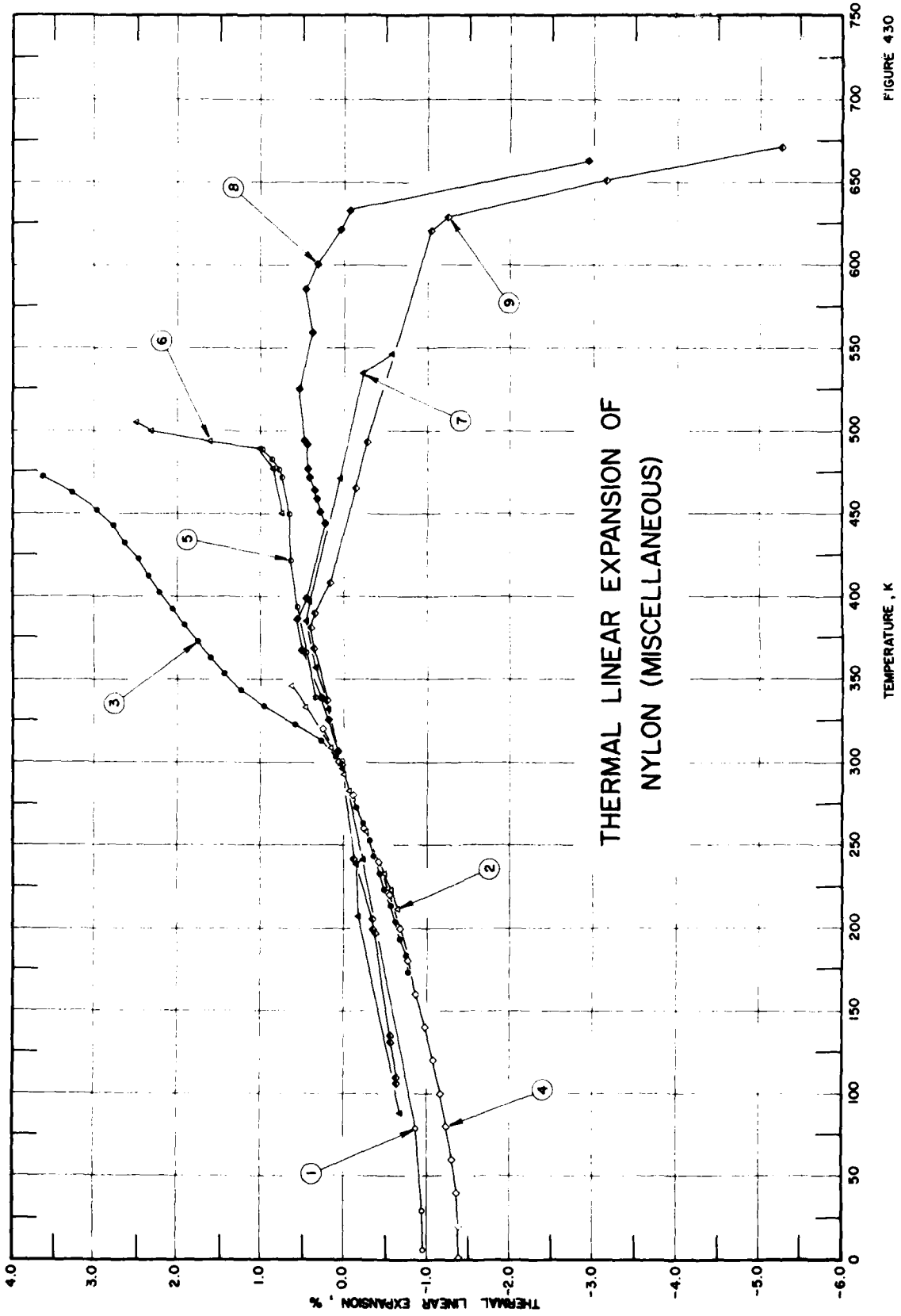

THERMAL LINEAR EXPANSION OF
NYLON (MISCELLANEOUS)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
1
2
3
4
5
6
7
8
9

FIGURE 430

SPECIFICATION TABLE 430. THERMAL LINEAR EXPANSION OF NYLON (MISCELLANEOUS)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	560	Buchna, H. and Haldmann, W.	1965	L	6-301		No details given.
2	540	Hagenbuch, L.M.	1950	L	212-346		No details given.
3	171	Asay, J.R.	1968		173-473	Nylon 6	Polyamide, repeating unit $[(CH_2)_5 - CO - NH -]$; density 1.14 g cm^{-3}; M.P. 498 K.
4	548	Laquer, H.L. and Head, E.L.	1952	L	0-320		Rod specimen 0.75 in. diameter; extruded before 1946; zero-point correction of -0.163% determined by graphical interpolation.
5	561	Haug, W.A.	1964	L	339-489	Nylon 610	Density of specimen 1.0839 g cm^{-3}; specimen of 0.8555 gm, 0.3251 cm diameter.
6	561	Haug, W.A.	1964	L	422-505	Nylon 610	Density 1.0839 g cm^{-3}; specimen of 0.8481 gm, 0.3251 cm diameter.
7	562	Engelke, W.T., Pyron, C.M., Jr., and Pears, C.D.	1967	L	88-598	Low-density phenolic nylon	Composite molded and consisted of 0.40 powdered 66 nylon (DuPont's Zytel 103), 0.25 phenolic resin (Union Carbide Corporation's BRP-5549), and 0.35 phenolic microballoons (Union Carbide Corporation's B/O-0930); nondegraded block specimen 12 in. in diameter and 4 in. thick; molding performed at maximum pressure of 2200 psi and temperature of 340 F, and post-cured at a temperature of 300 F; specimen No. 1 performed by immersing the quartz dilatometer in a dewar filled with nitrogen; expansion measured along direction perpendicular to the thickness; zero-point correction of 0.013% determined by graphical interpolation.
8	562	Engelke, W.T., et al.	1967	L	297-664	Low-density phenolic nylon	Similar to the above specimen except specimen No. 2 utilized a coil with several orifices drilled on the inside diameter which provided a surrounding spary of the liquid and gaseous nitrogen on the outside of the quartz tube; expansion measured along direction perpendicular to the thickness; zero-point correction of -0.003% determined by graphical interpolation.
9	562	Engelke, W.T., et al.	1967	L	108-671	Low-density phenolic nylon	The above specimen; expansion measured along the direction of thickness; zero-point correction of 0.022% determined by graphical interpolation.

DATA TABLE 430. THERMAL LINEAR EXPANSION OF NYLON (MISCELLANEOUS)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
6	-0.964
29	-0.949
79	-0.874
301	0.002
CURVE 2	
212	-0.650
223	-0.571
233	-0.496
234	-0.490*
258	-0.283
283	-0.086
293	0.000
308	0.150
333	0.462
346	0.614
CURVE 3 ‡	
173	-0.784
183	-0.732
193	-0.675
203	-0.612
213	-0.551
223	-0.489
233	-0.424
243	-0.364
253	-0.304
263	-0.239
273	-0.164
283	-0.084*
293	0.000*
303	0.100
313	0.275
323	0.596
333	0.956
343	1.231
353	1.439
363	1.608
373	1.761
383	1.911
393	2.058
403	2.204
413	2.346
423	2.487
433	2.625

T	$\Delta L/L_0$
CURVE 3 (cont.) ‡	
443	2.774
453	2.982
463	3.286
473	3.634
CURVE 4	
0	-1.391
20	-1.381
40	-1.354
60	-1.310
80	-1.249
100	-1.174
120	-1.090
140	-0.998
160	-0.898
180	-0.791
200	-0.675
220	-0.550
240	-0.414
260	-0.267
273	-0.163*
280	-0.109
300	0.059
320	0.246
CURVE 5	
339	0.332
366	0.453
394	0.565
422	0.622
450	0.660
472	0.741
477	0.793
483	0.867
489	0.996
CURVE 6	
422	0.62*
450	0.74
477	0.85
489	1.01
494	1.60
500	2.32
505	2.50

T	$\Delta L/L_0$
CURVE 7	
88.2	-0.691
207.0	-0.187
238.5	-0.177
241.1	-0.224
296.2	0.013
332.9	0.178
257.0	0.330
385.6	0.467
397.1	0.415
471.2	0.056
535.4	-0.224
597.9	-0.561
CURVE 8	
297.1	0.022*
306.6	0.075
325.4	0.189
338.2	0.280
367.9	0.504
386.1	0.570
398.2	0.442
444.8	0.228
451.2	0.292
459.8	0.333
464.0	0.363
472.4	0.414
477.6	0.430
492.1	0.451
494.6	0.498
525.4	0.533
559.6	0.398
585.7	0.460
600.7	0.318
620.7	0.040
633.6	-0.074
663.7	-2.946
CURVE 9	
107.6	-0.628
110.1	-0.628
131.7	-0.585
134.8	-0.565
197.9	-0.382
199.3	-0.359
205.5	-0.336

T	$\Delta L/L_0$
CURVE 9 (cont.)	
241.8	-0.126
297.3	0.010*
298.7	-0.003
299.0	0.050*
337.6	0.209
368.5	0.350
381.5	0.393
390.7	0.341
408.2	0.159
465.5	-0.154
493.7	-0.291
620.9	-1.047
629.5	-1.249
651.8	-3.143
671.3	-5.271

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

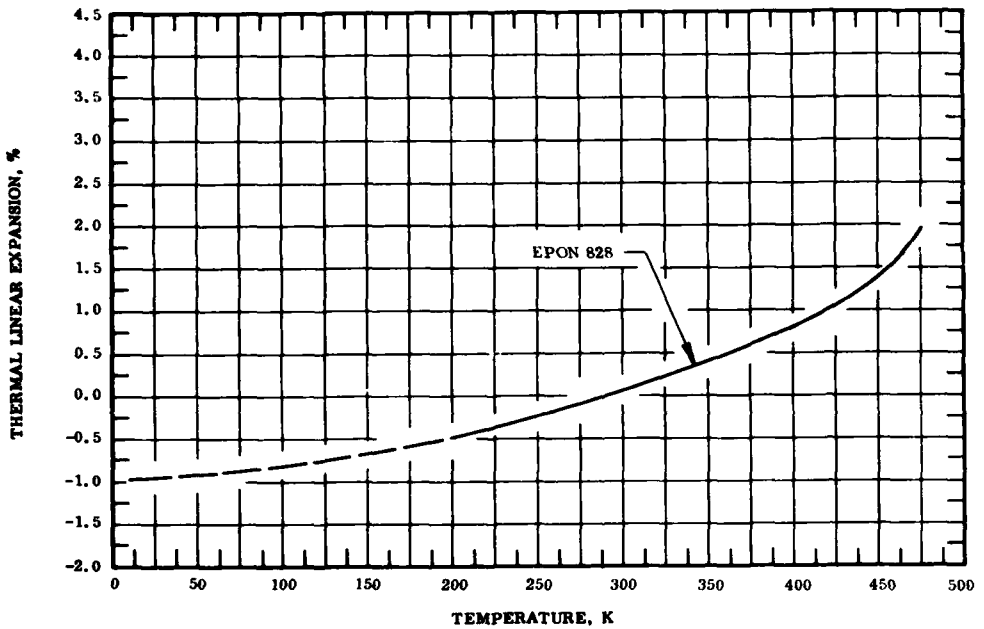
DATA TABLE 430. COEFFICIENT OF THERMAL LINEAR EXPANSION OF NYLON (MISCELLANEOUS)

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 3*,‡	
173	50.20
183	53.00
193	62.40
203	62.50
213	59.30
223	66.00
233	62.50
243	59.00
253	59.70
263	70.80
273	80.10
283	78.20
293	90.60
303	110.10
313	239.80
323	401.20
333	319.00
343	230.80
353	185.40
363	153.60
373	151.20
383	148.80
393	146.40
403	144.10
413	141.50
423	139.60
433	137.00
443	160.80
453	255.80
463	350.80
473	345.90

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

FIGURE AND TABLE NO. 431R. RECOMMENDED VALUES FOR THERMAL LINEAR EXPANSION OF EPOXY RESIN



RECOMMENDED VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

T	$\Delta L/L_0$	α
10	-0.965†	7
25	-0.952†	9
50	-0.923†	14
75	-0.883†	18
100	-0.832†	23
125	-0.770†	28
150	-0.795†	33
175	-0.605†	38
200	-0.502	44
225	-0.386	49
250	-0.255	55
275	-0.109	61
293	0.000	62
325	0.215	63
350	0.375	64
375	0.545	75
400	0.758	98
425	1.070	130
450	1.347	173
475	1.950	

† Provisional values

REMARKS

The recommended values for the Epon 828 are based on the data for the cured samples (curves 2-4, 10, 12 and 25) and are considered accurate to within ± 5% at temperatures above 200 K and ± 10% below 200 K. These values are represented approximately by the following equation:

$$\Delta L/L_0 = -0.706 - 3.041 \times 10^{-3}\, T + 2.409 \times 10^{-5}\, T^2 - 1.866 \times 10^{-8}\, T^3 \qquad (200\text{-}375\ K)$$

The tabulated values for the coefficient of thermal expansion are obtained primarily by differentiating the above equation and are considered accurate to about ± 10%. The data for Avcoat Epoxy Resin (curves 22 and 23) and Castable Epoxy Resin (curve 24) are considerably higher than those for Epon 828.

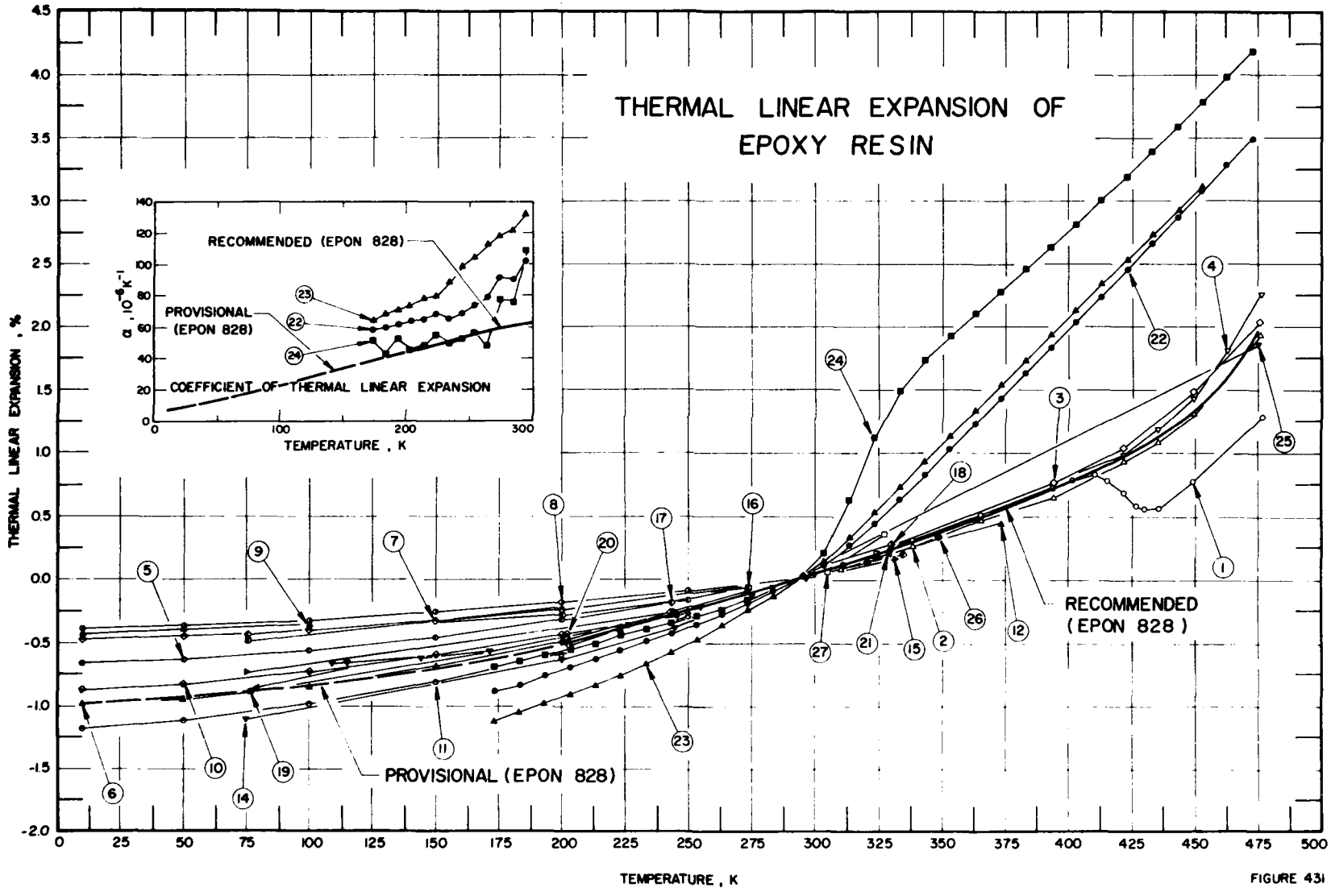

THERMAL LINEAR EXPANSION OF
EPOXY RESIN
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
RECOMMENDED (EPON 828)
PROVISIONAL (EPON 828)
RECOMMENDED
(EPON 828)
PROVISIONAL (EPON 828)
α , 10⁻⁶K⁻¹
COEFFICIENT OF THERMAL LINEAR EXPANSION
TEMPERATURE , K

FIGURE 431

SPECIFICATION TABLE 431. THERMAL LINEAR EXPANSION OF EPOXY RESIN

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	568	Denman, G. L.	1965	L	298–477	Epon 828	Pure epoxy resin cast; zero-point correction of 0.037% determined by graphical extrapolation.
2	568	Denman, G. L.	1965	L	477–298	Epon 828	The above specimen; expansion measured with decreasing temperature; zero-point correction of 0.761% determined by graphical extrapolation.
3	568	Denman, G. L.	1965	L	298–477	Epon 828	The above specimen; expansion measured after specimen had been heated and cooled once with increasing temperature; zero-point correction of 0.037% determined by graphical extrapolation.
4	568	Denman, G. L.	1965	L	477–300	Epon 828	The above specimen; expansion measured with decreasing temperature; zero-point correction of 0.292% determined by graphical extrapolation.
5	569	Hamilton, W. O., Greene, D. B., and Davidson, D. E.	1968	L	10–300	Torr Seal	71.43% base, 28.57% hardener, supplied by Varion Associates, Palo Alto, Calif.; after curing specimen machined into a rectangular block approximately 1.3 cm wide, 2.5 cm long, 1.9 cm high; zero-point correction of 0.026% determined by graphical interpolation.
6	569	Hamilton, W. O., et al.	1968	L	10–300	Resibond 907	66.67% part A, 33.33% part B, supplied by Resin Formulators Co., 3813 Hoke Ave., Culver City, Calif.; after curing specimen machined into a rectangular block approximately 1.3 cm wide, 2.5 cm long, 1.9 cm high; zero-point correction of 0.041% determined by graphical interpolation.
7	569	Hamilton, W. O., et al.	1968	L	10–300	Stanford 43	96.53% 43 Resin, 3.47% hardener, supplied by Grodan Mfg. and Sales, Inc. 10319-21 Grand River Ave., Detroit Michigan, after curing specimen machined into a rectangular block approximately 1.3 cm wide, 2.5 cm long, 1.9 cm high; zero-point correction of 0.022% determined by graphical interpolation.
8	569	Hamilton, W. O., et al.	1968	L	10–300	Stycast 2850 GT	96.06% Resin, 3.94% catalyst 11, supplied by Emerson and Cummings, Inc., Canton, Mass., after curing specimen machined into a rectangular block approximately 1.3 cm wide, 2.5 cm long, 1.9 cm high; zero-point correction of 0.016% determined by graphical interpolation.
9	569	Hamilton, W. O., et al.	1968	L	10–300	Stycast 2850 FT	95.24% resin, 4.76% catalyst 11, supplier of the specimen is the same as above and the dimensions of the specimen are the same as above; zero-point correction of 0.016% determined by graphical interpolation.
10	569	Hamilton, W. O., et al.	1968	L	10–300	Epon 828	75.00% 828 resin, 25.00% type U cure agt., supplied by Shell Chemical Co., plastics and Resins Div., Downey, Calif., after curing specimen machined into a rectangular block approximately 1.3 cm wide, 2.5 cm long, 1.9 cm high; zero-point correction of 0.037% determined by graphical interpolation.
11	569	Hamilton, W. O., et al.	1968	L	10–300	Epon 815	75.00% 815 resin, 25.00% type U cure agt., supplier of the specimen same as above, dimensions of the specimen same as above; zero-point correction of 0.048% determined by graphical interpolation.
12	570	Thomas, J. P.	1960	L	223, 373	Epon 828	Resin (lot 9AHJ3); obtained from Shell Chemical Company, New York, N. Y.; Tinius olsen quartz tube dilatometer and dial gage used.
13*	571	Kasai, N.	1968	X	0–60		Rod-form specimen, about 2 cm long, 8 mm diameter; this curve is here reported using the first given temperature (0 K) as reference temperature at which $\Delta L/L_0 = 0$.

* Not shown in figure.

SPECIFICATION TABLE 431. THERMAL LINEAR EXPANSION OF EPOXY RESIN (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
14	572	Marinace, J.C., Morehead, F., Rupprecht, H., Stern, F., and Woodall, J.	1968		75-297	Stycast 1266	Stycast 1266 resin obtained from Emerson and Cuming Co., zero-point correction of 0.013%.
15	572	Marinace, J.C., et al.	1968		75-332	Stycast 1266	7% SiO_2 powder added to the above specimen; zero-point correction of 0.007%.
16	572	Marinace, J.C., et al.	1968		76-293	Stycast 2850	Stycast 2850 FT from the Emerson and Cuming Company.
17	572	Marinace, J.C., et al.	1968		76-334	Stycast 2850	The above specimen; second measurement after 45 days.
18	572	Marinace, J.C., et al.	1968		203-330		Dow DER 321 specimen; zero-point correction of 0.028%.
19	572	Marinace, J.C., et al.	1968		77-324		The above specimen; second measurement after 16 days; zero-point correction of 0.028%.
20	572	Marinace, J.C., et al.	1968		202-329		Dow DER 322 specimen; zero-point correction of 0.037%.
21	572	Marinace, J.C., et al.	1968		78-329		Second specimen; similar to the above specimen; zero-point correction of 0.039%.
22	171	Assay, J.R.	1968		173-473		Avcoat 1, light epoxy polyamide; density ~1.10 g cm^{-3}, Tg ~307 K.
23	171	Assay, J.R.	1968		173-473		Avcoat 19, light green elastomeric epoxy resin; density ~1.07 g cm^{-3}; Tg is 293 K; begins to decompose at 533 K.
24	171	Assay, J.R.	1968		173-473	C-124	Castable 124, discolored opaque epoxy; density 1.23 g cm^{-3}; Tg is 311.0 K.
25	573	General Electric Co.	1964	V	109-475		Shell epon 828; cured 2 hr at 366 K, 4 hr at 394 K, 6 hr at 422 K; soaked 30 min at 116 K, then expansion measured with temperature increasing at 0.56 C per min; zero-point correction of -0.667% determined by graphical interpolation.
26	541	Aciteili, M.A., Gumby, W.L., and Naujokas, A.A.	1966	I	296-348	DOW-QX-2444	Material suitably worked to form tripod placed in furnace of instrument.
27	541	Aciteili, M.A., et al.	1966	I	296-327	Maraglas 555	Similar to the above specimen.

DATA TABLE 431. THERMAL LINEAR EXPANSION OF EPOXY RESIN

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
298	0.037
311	0.115
338	0.301
366	0.506
394	0.726
402	0.789
411	0.817
416	0.783
422	0.698
427	0.592
430	0.567
436	0.568
449	0.739
477	1.290
CURVE 2	
477	1.930
449	1.310
436	1.090
422	0.919
394	0.650
366	0.438
338	0.261
311	0.086
298	0.025*
CURVE 3	
298	0.037*
311	0.115*
338	0.301*
366	0.516*
394	0.753
422	1.040
449	1.480
477	2.040
CURVE 4	
477	2.260
463	1.810
449	1.430
436	1.190
422	0.987
394	0.708*
366	0.475*

T	$\Delta L/L_0$
CURVE 4 (cont.)	
338	0.276*
310	0.107*
300	0.044
CURVE 5	
10	-0.654
50	-0.628
100	-0.559
150	-0.458
200	-0.320
250	-0.163
300	0.026*
CURVE 6	
10	-0.999
50	-0.964
100	-0.856
150	-0.693
200	-0.487
250	-0.253
300	0.041*
CURVE 7	
10	-0.478
50	-0.455
100	-0.400
150	-0.327
200	-0.245
250	-0.133*
300	0.022*
CURVE 8	
10	-0.390
50	-0.373
100	-0.326
150	-0.263
200	-0.189
250	-0.098
300	0.016*
CURVE 9	
10	-0.416

T	$\Delta L/L_0$
CURVE 9 (cont.)	
50	-0.399
100	-0.352
150	-0.333*
200	-0.208*
250	-0.100*
300	0.016*
CURVE 10	
10	-0.875
50	-0.826
100	-0.730
150	-0.595
200	-0.431
250	-0.230*
300	0.037*
CURVE 11	
10	-1.181
50	-1.124
100	-0.993
150	-0.810
200	-0.587
250	-0.293
300	0.048*
CURVE 12	
223	-0.391
373	0.440
CURVE 13*,†	
0	0.000
20	0.010
40	0.039
60	0.078
CURVE 14	
75	-1.105
201	-0.634
244	-0.385
275	-0.131
293	0.000
297	0.018*

T	$\Delta L/L_0$
CURVE 15	
75	-0.747
201	-0.413*
244	-0.255
273	-0.100
293	0.000*
332	0.166
CURVE 16	
76	-0.489
201	-0.301*
273	-0.074
293	0.000*
CURVE 17	
76	-0.447
201	-0.284
243	-0.181
273	-0.051*
293	0.000*
298	0.005*
334	0.200
CURVE 18	
203	-0.520
243	-0.264
293	0.000*
330	0.280
CURVE 19	
77	-0.892
202	-0.484
243	-0.280*
274	-0.106*
293	0.000*
298	0.028*
324	0.202
CURVE 20	
202	-0.428
245	-0.275
275	-0.070*
293	0.000*
329	0.239

T	$\Delta L/L_0$
CURVE 21	
78	-0.858
202	-0.507
245	-0.297*
275	-0.094*
293	0.000*
298	0.039*
329	0.223
CURVE 22‡	
173	-0.876
183	-0.816
193	-0.754
203	-0.691
213	-0.626
223	-0.559
233	-0.492
243	-0.424
253	-0.352
263	-0.275
273	-0.189
283	-0.097
293	0.000*
303	0.121
313	0.270
323	0.444
333	0.637
343	0.834
353	1.032
363	1.234
373	1.436
383	1.638
393	1.840
403	2.043
413	2.246
423	2.453
433	2.662
443	2.869
453	3.080
463	3.288
473	3.490
CURVE 23‡	
173	-1.119
183	-1.052
193	-0.982

T	$\Delta L/L_0$
CURVE 23 (cont.)‡	
203	-0.909
213	-0.833
223	-0.754
233	-0.670
243	-0.575
253	-0.473
263	-0.364
273	-0.248
283	-0.127
293	0.000*
303	0.150
313	0.332
323	0.530
333	0.731
343	0.932
353	1.132
363	1.332
373	1.532
383	1.731
393	1.931
403	2.136
413	2.340
423	2.535
433	2.727
443	2.917
453	3.106
463	3.297*
473	3.489*
CURVE 24‡	
173	-0.696
183	-0.648
193	-0.599
203	-0.550
213	-0.502
223	-0.449
233	-0.396
243	-0.343
253	-0.288
263	-0.235
273	-0.172
283	-0.094*
293	0.000*
303	0.212
313	0.633
323	1.123

* Not shown in figure.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 431. THERMAL LINEAR EXPANSION OF EPOXY RESIN (continued)

T	$\Delta L/L_0$
CURVE 24 (cont.)‡	
333	1.492
343	1.730
353	1.920
363	2.105
373	2.284
383	2.463
393	2.643
403	2.823
413	3.007
423	3.196
433	3.390
443	3.588
453	3.787
463	3.986
473	4.185
CURVE 25	
109	-0.667
116	-0.654
144	-0.622
172	-0.563
200	-0.472*
227	-0.355
255	-0.217
283	-0.063
311	0.111*
339	0.285
366	0.487*
394	0.738*
422	1.065*
450	1.455*
475	1.850
CURVE 26	
296	0.014
321	0.137
348	0.330
CURVE 27	
296	0.016*
305	0.066
327	0.350

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 431. COEFFICIENT OF THERMAL LINEAR EXPANSION OF EPOXY RESIN

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 22‡	
173	59.1
183	60.8
193	62.5
203	64.2
213	65.8
223	68.9
233	65.0
243	69.9
253	74.7
263	79.6
273	92.2
283	91.0
293	103.4
303	138.6*
313	160.4*
323	187.4*
333	198.5*
343	195.8*
353	199.8*
363	203.5*
373	201.1*
383	201.8*
393	202.4*
403	203.1*
413	203.7*
423	211.0*
433	205.7*
443	208.3*
453	214.2*
463	202.1*
473	202.2*
CURVE 23‡	
173	65.1
183	68.6
193	71.7
203	73.8
213	78.7
223	79.1
233	89.2
243	99.7
253	104.4
263	114.1
273	118.7
283	122.1
293	132.6
303	167.8*
313	195.2*
323	200.8*
333	201.5*
343	200.3*
353	200.0*
363	200.1*
373	200.5*
383	198.0*
393	200.9*
403	210.0*
413	198.0*
423	192.0*
433	191.0*
443	189.0*
453	189.9*
463	192.1*
473	192.1*
CURVE 24‡	
173	52.1
183	44.0
193	53.0
203	46.0
213	49.5
223	55.9
233	50.9
243	53.9
253	57.0
263	48.9
273	78.1
283	77.6
293	109.8
303	314.7*
313	527.8*
323	451.9*
333	284.9*
343	191.4*
353	188.3*
363	182.5*
373	175.5*
383	181.6*
CURVE 24 (cont.)‡	
393	178.3*
403	182.9*
413	184.6*
423	192.8*
433	196.3*
443	199.4*
453	199.0*
463	198.6*
473	200.2*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 432. THERMAL LINEAR EXPANSION OF PHENOLIC RESIN

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	568	Denman, G. L.	1965	L	298-477	CTL-91-LD	Pure specimen cast; expansion measured with increasing temperature at a rate of 0.83 C per min; zero-point correction of 0.081%.
2*	568	Denman, G. L.	1965	L	477-297	CTL-91-LD	The above specimen; expansion measured with decreasing temperature at a rate of 0.83 C per min; zero-point correction of 3.11% determined by graphical extrapolation.
3*	568	Denman, G. L.	1965	L	298-477	CTL-91-LD	Similar to the above specimen measured with increasing temperature with temperature being held for 12 hr at intervals of 27.7 C; zero-point correction of 0.081% determined by graphical extrapolation.
4*	568	Denman, G. L.	1965	L	298-477	CTL-91-LD	Similar to the above specimen except expansion measured after specimen had been heated and cooled twice; zero-point correction of 0.050% determined by graphical extrapolation.
5*	568	Denman, G. L.	1965	L	477-298	CTL-91-LD	The above specimen; expansion measured with decreasing temperature; zero-point correction of 0.071% determined by graphical extrapolation.
6*	171	Asay, J.R.	1968		273-473	RAD-60	Black carbonaceous rigid material; density 1.41 g cm^{-3}; expansion measured parallel to axis.
7*	171	Asay, J.R.	1968		273-473	RAD-60	The above specimen; expansion measured perpendicular to axis.

* No figure given.

DATA TABLE 432. THERMAL LINEAR EXPANSION OF PHENOLIC RESIN

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
298	0.081
311	0.251
338	0.471
353	0.491
366	0.431
377	0.291
383	0.121
394	-0.459
402	-0.669
408	-0.769
422	-0.829
449	-0.829
477	-0.829
CURVE 2*	
477	1.70
449	1.02
422	0.51

T	$\Delta L/L_0$
CURVE 2 (cont.)*	
394	0.25
366	0.13
338	0.10
311	0.05
297	0.01
CURVE 3*	
298	0.081
311	0.251
338	0.471
352	0.481
361	0.441
366	0.331
374	0.081
380	-0.239
383	-0.519
388	-0.839
394	-1.030

T	$\Delta L/L_0$
CURVE 3 (cont.)*	
408	-1.300
422	-1.440
449	-1.710
477	-1.920
CURVE 4*	
298	0.052
311	0.162
338	0.392
366	0.582
394	0.852
422	1.150
449	1.470
477	1.770
CURVE 5*	
477	1.980

T	$\Delta L/L_0$
CURVE 5 (cont.)*	
449	1.650
422	1.320
394	0.992
366	0.702
338	0.422
311	0.162
298	0.052
CURVE 6*,‡	
273	-0.004
283	-0.002
293	0.000
303	0.001
313	0.003
323	0.003
333	0.004
343	0.006
353	0.007

T	$\Delta L/L_0$
CURVE 6 (cont.)*,‡	
363	0.010
373	0.014
383	0.019
393	0.026
403	0.035
413	0.047
423	0.061
433	0.078
443	0.096
453	0.115
463	0.138
473	0.162
CURVE 7*,‡	
273	0.008
283	0.004
293	0.000
303	-0.004

T	$\Delta L/L_0$
CURVE 7 (cont.)*,‡	
313	-0.008
323	-0.012
333	-0.016
343	-0.020
353	-0.024
363	-0.028
373	-0.031
383	-0.034
393	-0.037
403	-0.040
413	-0.042
423	-0.044
433	-0.046
443	-0.048
453	-0.049
463	-0.049
473	-0.049

DATA TABLE 432. COEFFICIENT OF THERMAL LINEAR EXPANSION OF PHENOLIC RESIN

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 6*,‡	
273	2.02
283	1.79
293	1.52
303	1.25
313	1.02
323	0.91
333	1.02
343	1.43
353	1.99
363	3.03
373	4.39
383	6.08
393	8.08
403	10.43
413	12.45

T	α
CURVE 6 (cont.)*,‡	
423	16.16
433	17.50
443	18.89
453	20.20
463	24.21
473	25.40
CURVE 7*,‡	
273	-3.83
283	-3.95
293	-4.00
303	-4.01
313	-4.10
323	-4.05

T	α
CURVE 7 (cont.)*,‡	
333	-4.00
343	-3.90
353	-3.76
363	-3.56
373	-3.36
383	-3.06
393	-2.85
403	-2.58
413	-2.20
423	-1.90
433	-1.53
443	-1.58
453	-0.65
463	-0.23
473	-0.03

* No figure given.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 433. THERMAL LINEAR EXPANSION OF POLYESTER RESIN

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	574	Haskins, J.F., Campbell, M.D., Hertz, J., and Percy, J.L.	1964	L	79-297	Unfilled polyester film, M-1	Polyethylene terephthalate film, (Mylar); formed and slow cooled; produced by E.I. DuPont deNemours, 100 resin; sample 0.5 in. long by stacking about 40 disks 0.168 in diameter from sheet of 0.014 in.; expansion measured in thickness direction.
2*	574	Haskins, J.F., et al.	1964	L	24-297	Unfilled polyester film, M-1	The above specimen; expansion measured normal to thickness; transverse direction.
3*	574	Haskins, J.F., et al.	1964	L	22-297	Unfilled polyester film, M-1	The above specimen; expansion measured normal to thickness, roll direction.

DATA TABLE 433. THERMAL LINEAR EXPANSION OF POLYESTER RESIN

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 2*		CURVE 3*		CURVE 3 (cont.)*	
79	-0.208	24	-0.618	22	-0.743	274	-0.062
90	-0.292	32	-0.611	57	-0.695	280	-0.050
102	-0.193	63	-0.568	79	-0.657	280	-0.041
114	-0.183	86	-0.529	103	-0.606	287	-0.021
126	-0.172	114	-0.476	121	-0.564	292	-0.013
138	-0.164	124	-0.449	139	-0.516	295	0.008
151	-0.154	133	-0.430	158	-0.467	297	0.013
160	-0.142	138	-0.414	178	-0.406		
174	-0.132	144	-0.397	193	-0.361		
187	-0.121	161	-0.356	215	-0.279		
197	-0.112	168	-0.340	221	-0.258		
207	-0.099	175	-0.323	225	-0.244		
218	-0.087	197	-0.275	228	-0.229		
230	-0.077	198	-0.268	232	-0.217		
243	-0.060	209	-0.237	241	-0.190		
253	-0.050	218	-0.214	245	-0.171		
266	-0.035	231	-0.182	250	-0.154		
270	-0.027	243	-0.159	254	-0.140		
279	-0.016	262	-0.100	257	-0.129		
285	-0.009	278	-0.047	263	-0.109		
291	-0.002	284	-0.032	265	-0.099		
296	0.004	297	0.016	268	-0.087		
297	0.005			273	-0.071		

* No figure given.

SPECIFICATION TABLE 434. THERMAL LINEAR EXPANSION OF RESINS (MISCELLANEOUS)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	571	Kasai, N.	1968	X	0-60	Bakelite	Rod specimen, about 2 cm long, 8 mm diameter; this curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.
2*	548	Laquer, H. L. and Head, E. L.	1952	L	0-380	Catalin	Rod specimen of 3/8 in. diameter; zero-point correction of -0.102% determined by graphical interpolation.
3*	548	Laquer, H. L. and Head, E. L.	1952	L	0-340	Araldite 501	Epoxy polymer made by the Ciba Co.; 40 gm material catalyzed by 2 cc. triethanolamine; 2 in. diameter casting resin cured for 8 hr at 393 K and 24 hr at 453 K; evaporation measured perpendicular to the axis of the flat cylinder; zero-point correction of -0.124% determined by graphical interpolation.
4*	548	Laquer, H. L. and Head, E. L.	1952	L	0-340	Laminac 4129	Unsaturated polyester resin made by American Cyanamide Co.; catalyzed with 0.3 weight percent tertbutyl hydroperoxide and casted into 3/4 in. diameter test tube; polymerization initiated during 48 hr; preliminary cure at room temperature and completed in 1 hr at 373 K; milky appearance; zero-point correction of -0.127% determined by graphical interpolation.
5*	548	Laquer, H. L. and Head, E. L.	1952	L	0-320	Selectron 5026	Unsaturated polyester made by Columbia Resins Division, Pittsburgh Plate Glass Co.; specimen transparent appearance; zero-point correction of -0.170% determined by graphical interpolation.
6*	541	Acitelli, M.A., Gumby, W. L., and Naujokas, A.A.	1966	I	299-413	Glass resin No. 650	Material suitably worked to form tripod placed in furnace of instrument.
7*	541	Acitelli, M.A., et al.	1966	I	294-330	Phenoxy resin	Specimen of linear epichlorohydrin-bisphenol A resin; material formed into tripod placed in furnace of instrument.
8*	541	Acitelli, M.A., et al.	1966	I	294-332	Glass resin No. 100 CR-39	Specimen of copolymer; material formed into tripod placed in furnace of instrument.
9*	541	Acitelli, M.A., et al.	1966	I	296-331	Glass resin No. 100	Similar to the above specimen.

* No figure given.

DATA TABLE 434. THERMAL LINEAR EXPANSION OF RESINS (MISCELLANEOUS)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*,†	
0	0.000
20	0.014
40	0.038
60	0.070
CURVE 2*	
0	-0.851
20	-0.837
40	-0.813
60	-0.781
80	-0.742
100	-0.697
120	-0.646
140	-0.590
160	-0.530
180	-0.466
200	-0.399
220	-0.327
240	-0.249
260	-0.163
273.2	-0.102
280	-0.069
300	0.038
320	0.169
340	0.317
360	0.492
380	0.707
CURVE 3*	
0	-1.063
20	-1.053
40	-1.024
60	-0.985
80	-0.937
100	-0.882
120	-0.821
140	-0.753
160	-0.664
180	-0.596
200	-0.507
220	-0.412
240	-0.310
260	-0.201
273.2	-0.124
CURVE 3 (cont.)*	
280	-0.083
300	0.044
320	0.180
340	0.331
CURVE 4*	
0	-1.203
20	-1.189
40	-1.155
60	-1.105
80	-1.043
100	-0.972
120	-0.894
140	-0.812
160	-0.725
180	-0.633
200	-0.536
220	-0.433
240	-0.324
260	-0.208
273.2	-0.127
280	-0.085
300	0.046
320	0.199
340	0.384
CURVE 5*	
0	-1.325
20	-1.311
40	-1.276
60	-1.223
80	-1.156
100	-1.081
120	-1.000
140	-0.913
160	-0.821
180	-0.724
200	-0.621
220	-0.511
240	-0.392
260	-0.262
273.2	-0.170
280	-0.118
300	0.063
320	0.309
CURVE 6*	
299	0.09
380	1.31
413	1.77
CURVE 7*	
294	0.005
311	0.093
330	0.218
CURVE 8*	
294	0.007
304	0.075
332	0.430
CURVE 9*	
296	0.026
303	0.090
331	0.480

* No figure given.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

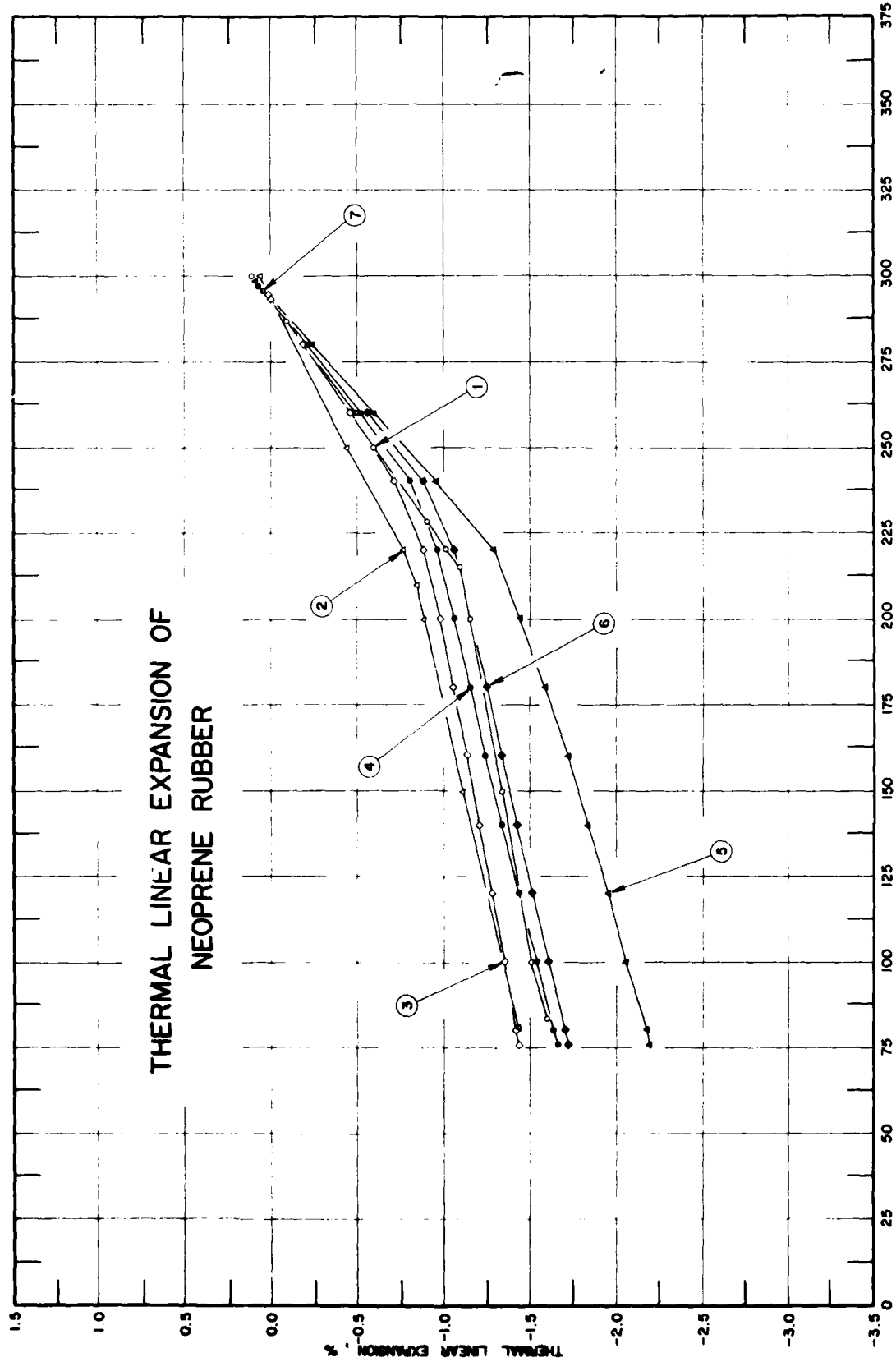

THERMAL LINEAR EXPANSION OF
NEOPRENE RUBBER
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
1
2
3
4
6
7

FIGURE 435

SPECIFICATION TABLE 435. THERMAL LINEAR EXPANSION OF NEOPRENE RUBBER

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	576	Weitzel, D.H., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1964	V/L	83-300		Polymer chains oriented with the expansion direction measured; zero-point correction of -1.60% determined by graphical interpolation.
2	576	Weitzel, D.H., et al.	1964	V/L	81-300		Specimen not oriented; zero-point correction of -1.43% determined by graphical interpolation.
3	538	Weitzel, D.H., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1960	L	76-294	IV-8B	Chloroprene, Neoprene WRT; obtained from DuPont; cured 20 min at 427 K; zero-point correction of -0.012%.
4	538	Weitzel, D.H., et al.	1960	L	76-297	IV-10A	Similar to the above specimen; cured 35 min at 427 K; zero-point correction of -0.074%.
5	538	Weitzel, D.H., et al.	1960	L	76-298	IV-10B	Similar to the above specimen; zero-point correction of -0.096%.
6	538	Weitzel, D.H., et al.	1960	L	76-297	IV-10C	Chloroprene, Neoprene GN; obtained from DuPont; cured 35 min at 427 K; zero-point correction of -0.084%.
7	538	Weitzel, D.H., et al.	1960	L	76-296	IV-10D	Chloroprene, Neoprene W; obtained from DuPont; cured 35 min at 427 K; zero-point correction of -0.048%.

DATA TABLE 435. THERMAL LINEAR EXPANSION OF NEOPRENE RUBBER

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
83	-1.60
100	-1.52
150	-1.34
200	-1.15
215	-1.08
221	-1.02
228	-0.908
250	-0.595
287	-0.095
300	0.111
CURVE 2	
81	-1.43
100	-1.52*
150	-1.12
200	-0.896
210	-0.842
220	-0.764
250	-0.448
300	0.073
CURVE 3	
76	-1.446
80	-1.426
100	-1.351
120	-1.280
140	-1.205
160	-1.130
180	-1.056
200	-0.980
220	-0.884
240	-0.708
260	-0.459
280	-0.191
293	0.000
294	0.012
CURVE 4	
76	-1.660
80	-1.630
100	-1.535
120	-1.436
140	-1.341
160	-1.243
180	-1.156
200	-1.069
220	-0.971
240	-0.801
260	-0.522
280	-0.206
293	0.000*
297	0.074
CURVE 5	
76	-2.198
80	-2.177
100	-2.066
120	-1.959
140	-1.846
160	-1.723
180	-1.584
200	-1.449
220	-1.283
240	-0.960
260	-0.588
280	-0.223
293	0.000*
298	0.096
CURVE 6	
76	-1.722
80	-1.700
100	-1.603
120	-1.513
140	-1.429
160	-1.337
180	-1.250
200	-1.157*
220	-1.065
240	-0.887
260	-0.554
280	-0.214*
293	0.000*
297	0.084*
CURVE 7	
76	-1.654*
80	-1.632*
100	-1.546*
120	-1.446*
140	-1.344*
160	-1.249*
180	-1.158*
200	-1.068*
220	-0.966*
240	-0.782*
260	-0.491
280	-0.199*
293	0.000*
296	0.048

* Not shown in figure.

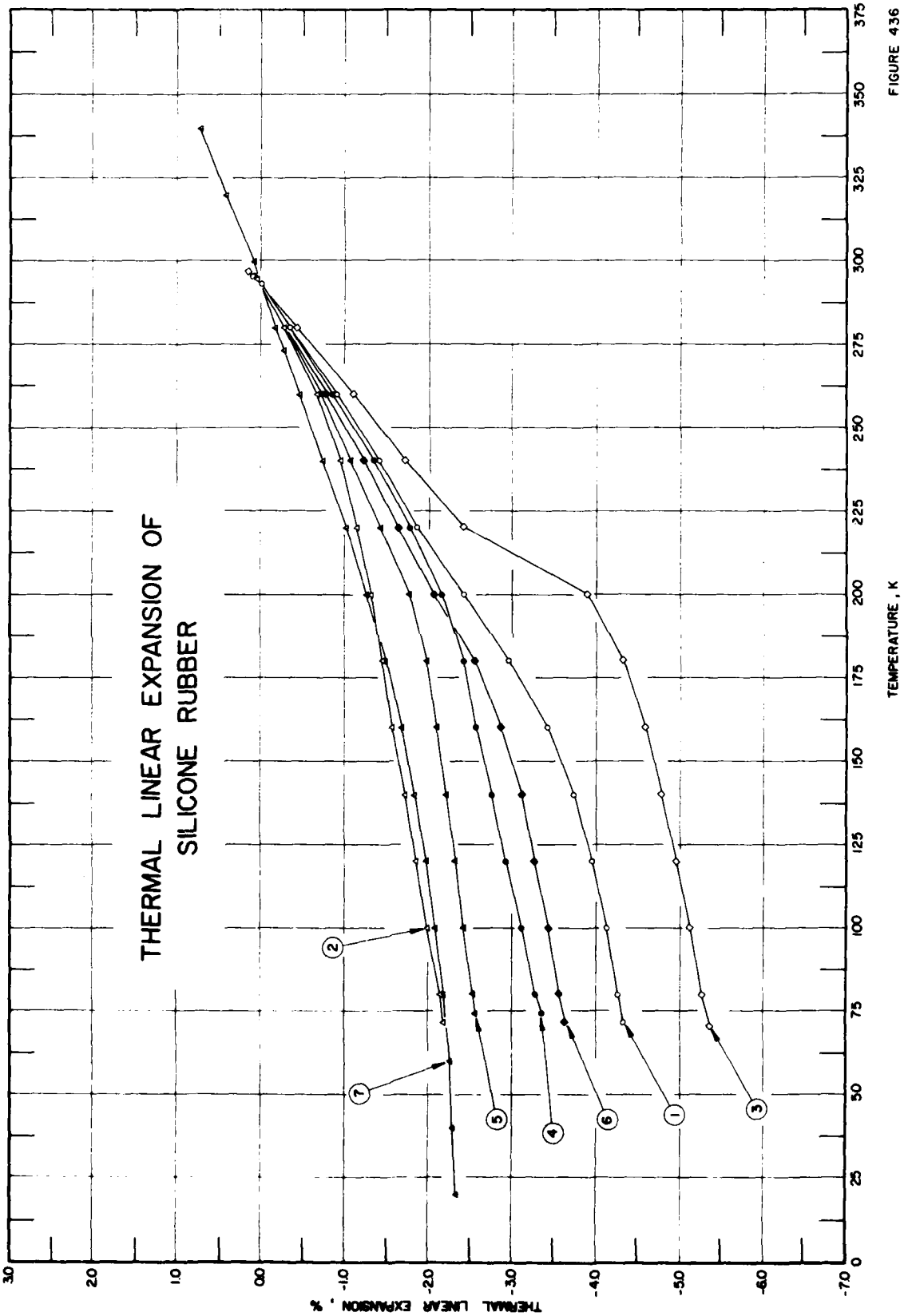

THERMAL LINEAR EXPANSION OF
SILICONE RUBBER
THERMAL LINEAR EXPANSION , %
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
TEMPERATURE , K
1
2
3
4
5
6
7

FIGURE 436

SPECIFICATION TABLE 436. THERMAL LINEAR EXPANSION OF SILICONE RUBBER

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	538	Weitzel, D.H., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1963	L	72-296	Silastic X30028 V-A2B	Specimen obtained from Dow Corning Corp.; methyl silicone modified with 30 mole percent vinyl; cured 10 min at 400 K; zero-point correction of -0.107%.
2	538	Weitzel, D.H., et al.	1963	L	72-294	Silastic X30002 V-A2C	Specimen obtained from Dow Corning Corp.; methyl silicone modified with 50 mole percent vinyl; cured 10 min at 400 K; zero-point correction of -0.040%.
3	538	Weitzel, D.H., et al.	1963	L	71-297	Silastic 400 V-A2A	Specimen obtained from Dow Corning Corp.; straight methyl silicone; cured 10 min at 400 K; zero-point correction of -0.145%.
4	538	Weitzel, D.H., et al.	1963	L	74-296	V-28A	Fluorinated silicone, fillers added by manufacturer (unspecified), cured 20 min at 389 K, post cure 24 min at 422 K; zero-point correction of -0.079%.
5	538	Weitzel, D.H., et al.	1963	L	74-294	V-28B	Cyanosilicone, fillers added by manufacturer (unspecified), cured 20 min at 444 K, post cured 24 min at 449 K; zero-point correction of -0.040%.
6	538	Weitzel, D.H., et al.	1963	L	72-295	V-A2D	Silicone X-0069; specimen obtained from Dow Corning Corp.; fillers added by manufacturer; cured 10 min at 395 K; post cured 16 hr at 522 K; zero-point correction of -0.062%.
7	548	Laquer, H.L. and Head, E.L.	1952	L	0-340	Silastic 160	Silicone rubber; made by Dow Corning Corp.; molded in plate mold under pressure 200 psi at 393 K for 10 min then cured 15 hr at 423 K, 7 hr at 473 K, 17 hr at 523 K to yield material of hardness 77 on shore A_2 scale; specimen of square cross-section cut from 0.175 in. thick sheet; reported error ±3-6%.

DATA TABLE 436. THERMAL LINEAR EXPANSION OF SILICONE RUBBER

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
72	-4.315
80	-4.252
100	-4.115
120	-3.949
140	-3.732
160	-3.414
180	-2.957
200	-2.412
220	-1.877
240	-1.408
260	-0.905
280	-0.347
293	0.000
296	0.107
CURVE 2	
72	-2.192
80	-2.141
100	-1.994
120	-1.850
140	-1.712
160	-1.579
180	-1.446
200	-1.308
220	-1.147
240	-0.955
260	-0.674
280	-0.279
293	0.000*
294	0.040
CURVE 3	
71	-5.330
80	-5.259
100	-5.104
120	-4.936
140	-4.770
160	-4.571
180	-4.311
200	-3.898
220	-2.406
240	-1.708
260	-1.100
280	-0.419
293	0.000*
297	0.145
CURVE 4	
74	-3.352
80	-3.288
100	-3.104
120	-2.925
140	-2.751
160	-2.571
180	-2.403
200	-2.162
220	-1.789
240	-1.338
260	-0.863
280	-0.355*
293	0.000*
296	0.079
CURVE 5	
74	-2.550
80	-2.520
100	-2.410
120	-2.308
140	-2.203
160	-2.106
180	-1.993
200	-1.774
220	-1.418
240	-1.060
260	-0.706
280	-0.279*
293	0.000*
294	0.040*
CURVE 6	
72	-3.618
80	-3.551
100	-3.412
120	-3.264
140	-3.106
160	-2.865
180	-2.535
200	-2.074
220	-1.636
240	-1.218
260	-0.773
280	-0.299*
293	0.000*
295	0.062*
CURVE 7	
0	-2.322
20	-2.317
40	-2.297
60	-2.252
80	-2.182
100	-2.087
120	-1.972
140	-1.837
160	-1.677
180	-1.487
200	-1.267
220	-1.017
240	-0.742
260	-0.462
273.2	-0.277
280	-0.182
300	0.098
320	0.403
340	0.728

* Not shown in figure.

SPECIFICATION TABLE 437. THERMAL LINEAR EXPANSION OF RUBBERS (MISCELLANEOUS)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	538	Weitzel, D.H., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1963	L	76-295	IV-8A	Natural rubber (smoked sheet) cured 15 min at 427 K; zero-point correction of -0.046%.
2*	538	Weitzel, D.H., et al.	1963	L	76-294	IV-29A	Polyisoprene (coral) cured 20 min at 427 K; zero-point correction of -0.012%.
3*	538	Weitzel, D.H., et al.	1963	L	76-295	IV-29B	Cio-4-polybutadiene cured 30 min at 427 K; zero-point correction of -0.046%.
4*	538	Weitzel, D.H., et al.	1963	L	76-294	IV-14B	Similar to the above specimen, cured 20 min at 427 K; zero-point correction of -0.012%.
5*	538	Weitzel, D.H., et al.	1963	L	111-296	IV-A9A	Similar to the above specimen; zero-point correction of -0.059%.
6*	538	Weitzel, D.H., et al.	1963	L	76-296	IV-A9B	Similar to the above specimen; 1 percent unsaturated Nordel from DuPont, cured 60 min at 432 K; zero-point correction of -0.059%.
7*	548	Laquer, H.L. and Head, E.L.	1952	L	0-300	Hard rubber	Specimen 1 in. thick; stock item of shore hardness, 90 on A_2 seale; supplied by W.H. Salisbury and Co., Chicago, Ill.; zero-point correction of -0.269% determined by graphical interpolation.
8*	576	Weitzel, D.H., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1964	V/L	77-293	Natural rubber + Lithafrax	50.0 natural rubber, 50.0 lithafrax; obtained from Carborundum Co.; zero-point correction of -1.93%.
9*	576	Weitzel, D.H., et al.	1964	V/L	76-300	Adiprene C + Lithafrax	50.0 Adiprene C, 50.0 Lithafrax, zero-point correction of -1.67% determined by graphical interpolation.
10*	576	Weitzel, D.H., et al.	1964	V/L	75-293	Nitroso elastomer compound	Specimen obtained from A.S.D.; zero-point correction of -4.09%.
11*	576	Weitzel, D.H., et al.	1964	V/L	80-300	Halveg elastomer	Specimen manufactured by Halveg industries; zero-point correction of -2.12% determined by graphical interpolation.
12*	538	Weitzel, D.H., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1963	L	76-297	IX-11A	Epoxy rubber; specimen ET-9 obtained from Narmco; cured 1 hr at 394 K; Shore A hardness 90; zero-point correction of -0.104%.
13*	538	Weitzel, D.H., et al.	1963	L	76-297	IX-11B	Epoxy rubber; specimen L51 obtained from Narmco; cured 1 hr at 394 K; Shore A hardness 100; zero-point correction of -0.075%.
14*	576	Weitzel, D.H., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1964	V/L	75-300	9B1 Nordel	EPR rubber; ethylene propylene rubber; specimen manufactured by DuPont; zero-point correction of -2.84% determined by graphical interpolation.
15*	576	Weitzel, D.H., et al.	1964	V/L	75-300	9B2 Nordel	EPR rubber; similar to the above specimen; zero-point correction of -2.73% determined by graphical interpolation.
16*	538	Weitzel, D.H., Robbins, R.F., Ludtke, P.R., and Ohori, Y.	1963	L	76-296	EPR-40	EPR rubber; specimen cured 20 min at 427 K; zero-point correction of -0.059%.

* No figure given.

DATA TABLE 437. THERMAL LINEAR EXPANSION OF RUBBERS (MISCELLANEOUS)

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
76	-2.102
80	-2.083
100	-2.011
120	-1.931
140	-1.837
160	-1.737
180	-1.624
200	-1.488
220	-1.269
240	-0.941
260	-0.574
280	-0.217
293	0.000
295	0.046

CURVE 2*

T	$\Delta L/L_0$
76	-1.908
80	-1.887
100	-1.780
120	-1.680
140	-1.579
160	-1.481
180	-1.378
200	-1.271
220	-1.110
240	-0.843
260	-0.542
280	-0.228
293	0.000
294	0.012

CURVE 3*

T	$\Delta L/L_0$
76	-3.062
80	-3.031
100	-2.877
120	-2.735
140	-2.588
160	-2.412
180	-2.145
200	-1.767
220	-1.392
240	-1.016
260	-0.633
280	-0.245

CURVE 3 (cont.)*

T	$\Delta L/L_0$
293	0.000
295	0.046

CURVE 4*

T	$\Delta L/L_0$
76	-2.442
80	-2.418
100	-2.311
120	-2.209
140	-2.106
160	-1.990
180	-1.778
200	-1.475
220	-1.168
240	-0.864
260	-0.551
280	-0.237
293	0.000
294	0.012

CURVE 5*

T	$\Delta L/L_0$
111	-1.738
120	-1.691
140	-1.580
160	-1.480
180	-1.375
200	-1.268
220	-1.148
240	-0.988
260	-0.721
280	-0.312
293	0.000
296	0.059

CURVE 6*

T	$\Delta L/L_0$
76	-2.668
80	-2.640
100	-2.523
120	-2.414
140	-2.302
160	-2.181
180	-2.053
200	-1.874
220	-1.640

CURVE 6 (cont.)*

T	$\Delta L/L_0$
240	-1.276
260	-0.829
280	-0.356
293	0.000
296	0.059

CURVE 7*

T	$\Delta L/L_0$
0	-1.287
20	-1.276
40	-1.253
60	-1.226
80	-1.187
100	-1.141
120	-1.082
140	-1.014
160	-0.957
180	-0.847
200	-0.749
220	-0.638
240	-0.514
260	-0.377
273.2	-0.269
280	-0.194
300	0.104

CURVE 8*

T	$\Delta L/L_0$
77	-1.930
89	-1.920
100	-1.900
150	-1.730
188	-1.600
194	-1.580
200	-1.540
206	-1.500
213	-1.430
221	-1.340
227	-1.220
238	-1.040
250	-0.806
257	-0.681
271	-0.431
284	-0.181
293	0.000

CURVE 9*

T	$\Delta L/L_0$
76	-1.670
100	-1.630
126	-1.570
150	-1.490
186	-1.350
200	-1.280
218	-1.170
229	-1.050
237	-0.947
250	-0.741
267	-0.454
285	-0.168
300	0.112

CURVE 10*

T	$\Delta L/L_0$
75	-4.000
100	-3.810
150	-3.460
187	-3.190
195	-3.120
200	-3.070
206	-3.000
217	-2.850
224	-2.740
232	-2.590
244	-2.320
248	-2.190
251	-2.000
256	-1.500
260	-1.220
269	-0.862
279	-0.500
293	0.000

CURVE 11*

T	$\Delta L/L_0$
80	-2.120
100	-1.960
150	-1.540
200	-1.140
233	-0.844
241	-0.762
251	-0.621
285	-0.121
300	0.105

CURVE 12*

T	$\Delta L/L_0$
76	-2.043
80	-2.022
100	-1.912
120	-1.777
140	-1.635
160	-1.488
180	-1.334
200	-1.176
220	-1.016
240	-0.845
260	-0.621
280	-0.296
293	0.000
297	0.104

CURVE 13*

T	$\Delta L/L_0$
76	-1.552
80	-1.526
100	-1.428
120	-1.341
140	-1.254
160	-1.165
180	-1.085
200	-0.993
220	-0.873
240	-0.724
260	-0.525
280	-0.238
293	0.000
297	0.075

CURVE 14*

T	$\Delta L/L_0$
75	-2.84
88	-2.82
94	-2.80
100	-2.77
150	-2.48
173	-2.34
187	-2.25
195	-2.17
203	-2.08
211	-1.97
219	-1.84
231	-1.55

CURVE 14 (cont.)*

T	$\Delta L/L_0$
250	-1.05
259	-0.841
278	-0.341
300	0.159

CURVE 15*

T	$\Delta L/L_0$
75	-2.73
88	-2.71
94	-2.69
100	-2.66
150	-2.37
173	-2.23
187	-2.14
195	-2.06
203	-1.97
213	-1.87
221	-1.73
232	-1.45
242	-1.23
263	-0.733
283	-0.233
300	0.163

CURVE 16*

T	$\Delta L/L_0$
76	-2.867
80	-2.838
100	-2.692
120	-2.550
140	-2.415
160	-2.266
180	-2.132
200	-1.950
220	-1.699
240	-1.318
260	-0.867
280	-0.360
293	0.000
296	0.059

* No figure given.

10. COMPOSITES

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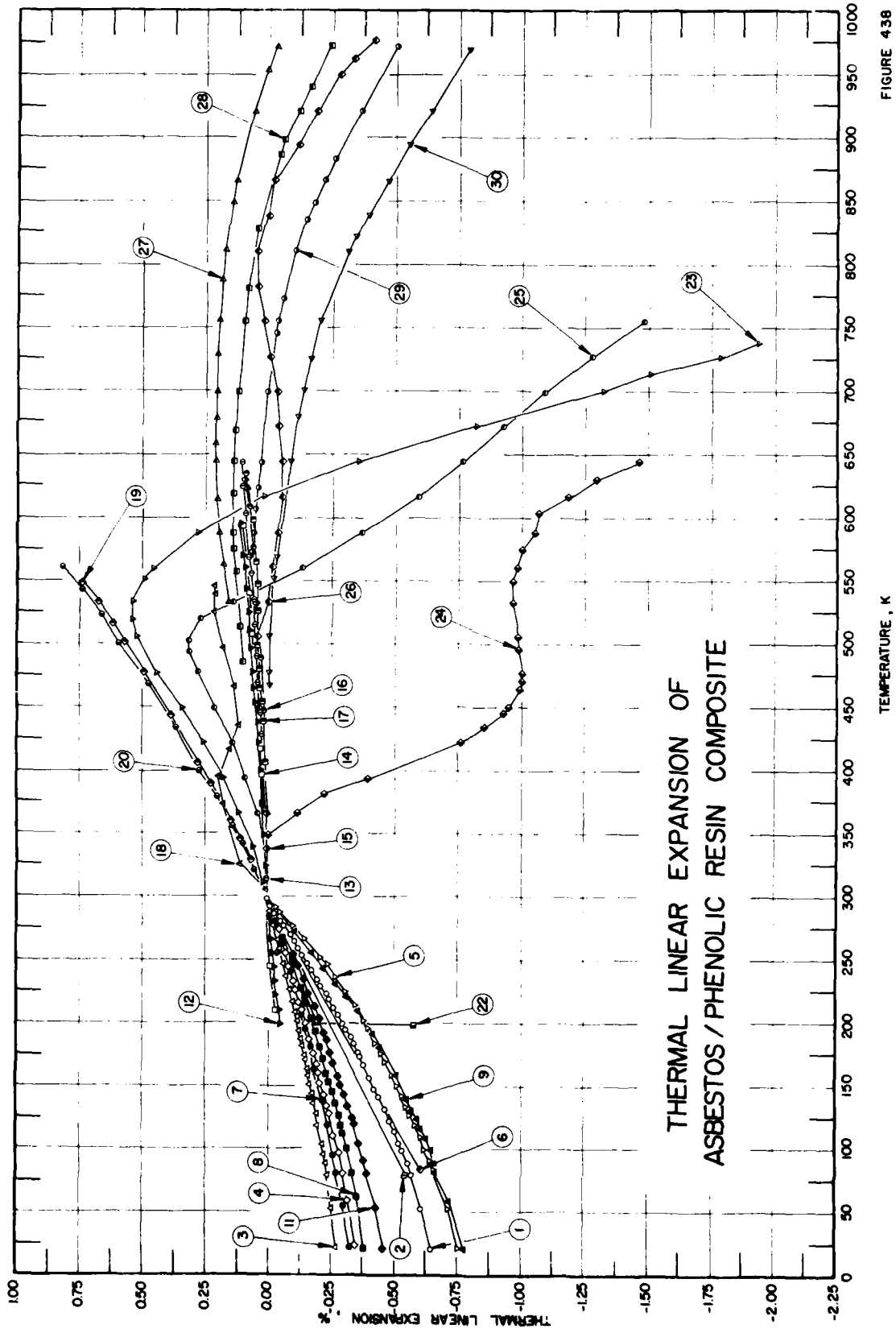

THERMAL LINEAR EXPANSION OF
ASBESTOS / PHENOLIC RESIN COMPOSITE
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
-1.75
-2.00
-2.25
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000

FIGURE 438

SPECIFICATION TABLE 438. THERMAL LINEAR EXPANSION OF ASBESTOS/PHENOLIC RESIN COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	574	Haskins, J.F., Campbell, M.D., Hertz, J., and Percy, J.L.	1964	L	20-298	Asbestos Reinforced Phenolic, N-1	Fiberite MX-5700, 25 psi molding pressure; reinforced fibers filled with phenolic microballoons; mat construction; observed shrinkage as a result of drying of the asbestos reinforcement by the dry helium purge in the chamber; expansion measured in the thickness direction; corrected sub-liquid nitrogen data; first run.
2	574	Haskins, J.F., et al.	1964	L	79, 298	Asbestos Reinforced Phenolic, N-1	The above specimen; third cycle.
3	574	Haskins, J.F., et al.	1964	L	21-297	Asbestos Reinforced Phenolic, N-2	Similar to the above specimen; sample taken from panel 4.5 in. x 0.125 in. x 7 in.; expansion measured in helium atmosphere, normal to thickness in the warp direction; corrected sub-liquid nitrogen recorded; first run.
4	574	Haskins, J.F., et al.	1964	L	23-297	Asbestos Reinforced Phenolic, N-2	The above specimen; expansion measured normal to thickness in the weave direction, corrected sub-liquid nitrogen; first run.
5	574	Haskins, J.F., et al.	1964	L	21-298	Asbestos Reinforced Phenolic, O-1	Similar to the above specimen; except 200 psi molding pressure; sub-liquid nitrogen data corrected; expansion measured in thickness direction; first run.
6	574	Haskins, J.F., et al.	1964	L	83, 298	Asbestos Reinforced Phenolic, O-1	The above specimen; fourth cycle.
7	574	Haskins, J.F., et al.	1964	L	21-297	Asbestos Reinforced Phenolic, O-2	Similar to the above specimen; sample 0.117 in. x 0.117 in. x 2 in. taken from panel 4.5 in. x 0.125 in. x 7 in.; expansion measured in helium atmosphere normal to thickness in the warp direction; corrected sub-liquid nitrogen data; first run.
8	574	Haskins, J.F., et al.	1964	L	21-297	Asbestos Reinforced Phenolic, O-2	The above specimen; expansion normal to thickness in the weave direction; first run.
9	574	Haskins, J.F., et al.	1964	L	20-297	Asbestos Reinforced Phenolic, P-1	Similar to the above specimen; chopped asbestos, random oriented, fiberrite MX-5700; sample taken from panel of 10 in. x 0.5 in. x 14 in.; corrected sub-liquid nitrogen data (-423 F); expansion measured in thickness direction; first run.
10*	574	Haskins, J.F., et al.	1964	L	80, 297	Asbestos Reinforced Phenolic, P-1	The above specimen; third cycle.
11	574	Haskins, J.F., et al.	1964	L	21-297	Asbestos Reinforced Phenolic, P-2	Similar to the above specimen; sample taken from panel of 4.5 in. x 0.125 in. x 7 in.; expansion measured normal to thickness direction; first run.
12	1053	Melonas, J.V., Covington, P.C., and Pears, C.D.	1958		199-595	Asbestos-Phenolic 9526D Laminate	Phenolic and Raybestos Manhattan 9526D fabric, fabricated by Brunswick-Balke-Collender Co.; nominal thickness 1/8 in.; specimen 1 in. wide and 7 in. long; curing process: (300 F) 422 K-1/2 hr at 400 psi, posture: (300 F) 422 K-4 hr and (350 F) 450 K-8 hr; 1st run in longitudinal direction with respect to the fabric lay up; density 78 lb ft^{-3}.

* Not shown in figure.

SPECIFICATION TABLE 438. THERMAL LINEAR EXPANSION OF ASBESTOS/PHENOLIC RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
13	1053	Melonas, J.V., Covington, P.C., and Pears, C.D.	1958		313-643		Second run of the above specimen in longitudinal direction.
14	1053	Melonas, J.V., et al.	1958		199-593		Same curing process as that of the above specimen; first run in the transverse direction with respect to the fabric lay up.
15	1053	Melonas, J.V., et al.	1958		295-629		Second run of the above specimen in transverse direction.
16	1053	Melonas, J.V., et al.	1958		199-634		Same curing process as that of the above specimen; first run in the diagonal direction with respect to the fabric lay up.
17	1053	Melonas, J.V., et al.	1958		250-598		Second run of the above specimen in diagonal direction.
18	1053	Melonas, J.V., et al.	1958		293-545		Same except disk specimen with 1 in. diameter and 7 1/6 in. thickness; same curing process as that of the above specimen; first run in thickness direction with respect to the fabric lay up.
19	1053	Melonas, J.V., et al.	1958		293-549		Second run of the above specimen in thickness direction.
20	1053	Melonas, J.V., et al.	1958		293-562		Third run in thickness direction.
21*	1053	Melonas, J.V., et al.	1958		293-199		Same except disk specimen 5 1/4 in. thick; same curing process as that of the above specimen; first run in thickness direction with respect to the fabric lay up; measured with decreasing temperature.
22	1053	Melonas, J.V., et al.	1958		293-198		Second run of the above specimen in thickness direction; measured with decreasing temp.
23	1054	Au, N.N., Scheyhing, E.K., and Summers, G.D.	1969		255-739		Specimen 0.325 in., conditioned for 40 hr at 300 F, 100% relative humidity, heating rate 8 C/min, expansion measured on dry specimen.
24	1054	Au, N.N., et al.	1969		255-644		Similar to the above specimen; expansion measured on wet specimen.
25	1054	Au, N.N., et al.	1969		255-755		Specimen 0.150 in., heating rate 100 C/min, expansion measured perpendicular to ply, average value of six specimens.
26	1054	Au, N.N., et al.	1969		255-1027		Similar to the above specimen; expansion measured parallel to ply.
27	1054	Au, N.N., et al.	1969		533-972		Similar to the above specimen; expansion measured perpendicular to ply with dry specimen.
28	1054	Au, N.N., et al.	1969		485-973		Similar to the above specimen; low wet specimen.
29	1054	Au, N.N., et al.	1969		477-973		Similar to the above specimen; nominal wet specimen.
30	1054	Au, N.N., et al.	1969		467-970		Similar to the above specimen; high wet specimen.

* Not shown in figure.

DATA TABLE 438. THERMAL LINEAR EXPANSION OF ASBESTOS/PHENOLIC RESIN COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
20	-0.649
53	-0.608
79	-0.571
88	-0.553
99	-0.530
104	-0.518
113	-0.502
122	-0.481
131	-0.464
141	-0.439
148	-0.424
157	-0.401
167	-0.378
173	-0.365
176	-0.359
183	-0.339
188	-0.328
194	-0.312
199	-0.294
206	-0.276
212	-0.260
218	-0.243
223	-0.227
229	-0.211
234	-0.194
241	-0.173
247	-0.151
253	-0.135
259	-0.119
264	-0.102
269	-0.087
276	-0.061
280	-0.045
286	-0.024
292	-0.004
298	0.026
CURVE 2	
79	-0.5465
298	0.026*
CURVE 3	
21	-0.273
53	-0.251
CURVE 3 (cont.)	
79	-0.233
88	-0.228
95	-0.220
103	-0.214
118	-0.199
128	-0.191
135	-0.183
144	-0.175
151	-0.167
158	-0.159
163	-0.154
170	-0.147
174	-0.141
181	-0.134
187	-0.130
193	-0.123
201	-0.114
203	-0.111*
208	-0.106
217	-0.097
221	-0.091*
226	-0.085
233	-0.076*
237	-0.071
242	-0.066*
247	-0.059
253	-0.052*
259	-0.044
265	-0.038
269	-0.033*
277	-0.023
280	-0.019*
288	-0.009
289	-0.005*
297	0.006*
CURVE 4	
23	-0.343
59	-0.315
80	-0.295
97	-0.278
103	-0.270*
110	-0.261
119	-0.249*
128	-0.240
CURVE 4 (cont.)	
134	-0.230
143	-0.221
152	-0.208
160	-0.198
167	-0.189
171	-0.183*
175	-0.178
182	-0.168*
187	-0.162
194	-0.153*
199	-0.144
205	-0.137*
210	-0.131
216	-0.121
221	-0.115*
226	-0.108
233	-0.097
239	-0.086*
244	-0.079
248	-0.071*
255	-0.065
259	-0.057*
265	-0.049*
269	-0.043*
274	-0.035
280	-0.021*
285	-0.011*
290	-0.003*
297	0.004*
CURVE 5	
21	-0.752
53	-0.714
83	-0.653
90	-0.638
99	-0.619
109	-0.601
118	-0.582
122	-0.572*
126	-0.562
133	-0.547
142	-0.528
150	-0.513
158	-0.491
168	-0.465
CURVE 5 (cont.)	
175	-0.447
180	-0.434*
184	-0.422
191	-0.407*
195	-0.395
201	-0.376
206	-0.362*
214	-0.345
218	-0.332*
224	-0.309
230	-0.291*
236	-0.271
241	-0.252*
246	-0.233
252	-0.209
258	-0.181*
266	-0.147
268	-0.132*
276	-0.099
280	-0.078*
287	-0.042
291	-0.009
298	0.030*
CURVE 6	
83	-0.6039
298	0.030*
CURVE 7	
21	-0.323
55	-0.294
80	-0.273
94	-0.259
101	-0.251*
109	-0.243*
118	-0.234
124	-0.227*
131	-0.221*
138	-0.213
145	-0.205*
153	-0.196*
163	-0.186
168	-0.180*
172	-0.174*
CURVE 7 (cont.)	
180	-0.166
184	-0.161*
189	-0.155*
194	-0.147
200	-0.141*
206	-0.132
213	-0.125*
217	-0.118*
223	-0.111*
228	-0.104*
233	-0.097*
240	-0.086
249	-0.077*
252	-0.071*
255	-0.064*
262	-0.055
244	-0.042*
274	-0.035*
276	-0.031*
280	-0.023
287	-0.012*
293	0.000
297	0.006*
CURVE 8	
21	-0.379
62	-0.350
80	-0.333
100	-0.313
112	-0.297
118	-0.287
126	-0.277
136	-0.265
146	-0.254
153	-0.242
160	-0.232
167	-0.222*
171	-0.216
175	-0.210*
181	-0.201
186	-0.195*
193	-0.184
196	-0.177*
203	-0.168
208	-0.161*
CURVE 8 (cont.)	
215	-0.149
220	-0.141*
227	-0.130
230	-0.123*
234	-0.113*
241	-0.102*
249	-0.091
252	-0.084*
257	-0.074*
262	-0.062*
267	-0.053
272	-0.042*
279	-0.027*
285	-0.015*
292	0.000*
297	0.012*
CURVE 9	
20	-0.774
59	-0.717
80	-0.669
90	-0.659*
98	-0.647
108	-0.625
116	-0.605
123	-0.586
130	-0.568
139	-0.550
149	-0.518*
158	-0.505
162	-0.485*
169	-0.469*
174	-0.452*
180	-0.436
185	-0.425*
191	-0.413
197	-0.388*
202	-0.372*
209	-0.352
213	-0.333*
220	-0.311
226	-0.286*
230	-0.269
237	-0.246*
243	-0.215

* Not shown in figure.

DATA TABLE 438. THERMAL LINEAR EXPANSION OF ASBESTOS/PHENOLIC RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 9 (cont.)	
248	-0.207*
255	-0.172
260	-0.155*
265	-0.130*
272	-0.100
277	-0.086*
282	-0.055*
287	-0.037*
293	0.000*
297	0.028*
CURVE 10*	
80	-0.655
297	0.028
CURVE 11	
21	-0.459
53	-0.429
80	-0.389
91	-0.381
98	-0.369*
104	-0.360
112	-0.349*
119	-0.337
125	-0.329
134	-0.315
144	-0.301
151	-0.289
158	-0.278
163	-0.264*
168	-0.257
176	-0.246
180	-0.238*
186	-0.231
192	-0.220
196	-0.212*
203	-0.200
207	-0.192*
213	-0.182
218	-0.172*
223	-0.158
229	-0.148*
235	-0.139
239	-0.127*
245	-0.114
248	-0.107*

T	$\Delta L/L_0$
CURVE 11 (cont.)	
254	-0.096
260	-0.082*
265	-0.070*
268	-0.061*
273	-0.052*
281	-0.031*
287	-0.014*
292	0.000*
297	0.011*
CURVE 12	
199	-0.048
210	-0.043
222	-0.037
233	-0.031
244	-0.026
255	-0.020
266	-0.014
283	-0.005
324	0.010
349	0.021
374	0.030
400	0.034
422	0.037
438	*0.043*
454	0.051
465	0.060
478	0.065
497	0.071
511	0.075
525	0.081
543	0.088
561	0.097
570	0.103
595	0.113
CURVE 13	
313	0.004
369	0.016
398	0.026*
428	0.028
445	0.033
469	0.041
490	0.047
515	0.056

T	$\Delta L/L_0$
CURVE 13 (cont.)	
535	0.061
556	0.073
573	0.081
603	0.098
624	0.107
643	0.110
CURVE 14	
199	-0.034*
210	-0.031
222	-0.029*
233	-0.024*
244	-0.019
255	-0.014*
266	-0.009*
283	-0.003*
347	0.018*
370	0.024*
397	0.031
417	0.035
436	0.041*
453	0.049*
463	0.054*
478	0.061*
497	*0.065**
509	0.069
526	0.075*
540	0.082
559	0.091*
569	0.095*
593	0.103
CURVE 15	
295	0.000*
337	0.006
365	0.011
395	0.020*
427	0.023*
444	0.029*
468	0.036*
489	0.041*
515	0.049*
533	0.056
554	0.064*
573	0.073

T	$\Delta L/L_0$
CURVE 15 (cont.)	
603	0.083*
623	0.090
629	0.090
CURVE 16	
199	-0.042*
210	-0.040*
222	-0.035*
233	-0.030*
244	-0.025*
255	-0.020*
266	-0.015*
283	-0.009*
338	0.009*
369	0.016*
399	0.023*
447	0.024
469	0.030*
489	0.036
515	0.043*
535	0.050*
557	0.060*
577	0.067
608	0.083
630	0.093*
634	0.096
CURVE 17	
250	0.015*
407	0.016
438	0.025
440	0.028*
454	0.030
464	0.036
480	0.036
499	0.041
513	0.042*
526	0.043
547	0.043
565	0.050
573	0.056*
598	0.065

T	$\Delta L/L_0$
CURVE 18	
293	0.000*
305	0.016
325	0.114
373	0.181
395	0.198
417	0.157
435	0.121
466	0.133
497	0.178
525	0.215
539	0.212
545	0.216
CURVE 19	
293	0.000*
302	0.010*
329	0.072
345	0.114
360	0.152
389	0.227
407	0.281
443	0.387
478	0.492
502	0.572
516	0.621
534	0.678
549	0.738
CURVE 20	
293	0.000*
321	0.055
341	0.105
356	0.145
379	0.202
400	0.275
434	0.369
468	0.476
500	0.585
523	0.667
543	0.742
562	0.818
CURVE 21*	
293	*0.000*
244	-0.061

T	$\Delta L/L_0$
CURVE 21 (cont.)*	
219	-0.133
203	-0.181
199	-0.195
CURVE 22	
293	0.000*
247	-0.071*
220	-0.147
200	-0.189
198	-0.575
CURVE 23	
255	-0.035
283	-0.012*
310	0.022
338	0.063
366	0.123
394	0.182
422	0.258
449	0.342
477	0.441
505	0.525
519	0.545
533	0.545
552	0.494
560	0.463
588	0.280
616	0.020
644	-0.356
672	-0.823
700	-1.324
714	-1.596
727	-1.786
739	-1.937
CURVE 24	
255	-0.024*
283	-0.005*
310	0.009*
338	-0.001*
348	-0.000
366	-0.115
382	-0.224
394	*-0.394*
422	-0.762

* Not shown in figure.

DATA TABLE 438. THERMAL LINEAR EXPANSION OF ASBESTOS/PHENOLIC RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 24 (cont.)	
434	-0.860
445	-0.929
449	-0.946
464	-0.993
470	-1.007
477	-1.007
495	-0.996
505	-0.985
533	-0.968
549	-0.968
560	-0.980
575	-1.005
588	-1.052
603	-1.064
616	-1.182
630	-1.298
644	-1.468
CURVE 25	
255	-0.018*
283	-0.003*
310	0.006*
338	0.021*
366	0.043
394	0.091
422	0.146
449	0.216
478	0.282
494	0.314
502	0.314
505	0.310*
520	0.272
533	0.147
560	-0.135
588	-0.374
616	-0.590
644	-0.769
672	-0.927
699	-1.090
727	-1.280
755	-1.482
CURVE 26	
255	-0.014*
283	-0.003*
311	0.004*
338	0.008*
366	0.012*
394	0.017*
422	0.033*
449	0.042*
477	0.049*
505	0.039
533	0.007
561	-0.014
588	-0.037
616	-0.050
644	-0.050
672	-0.040
699	-0.029
727	-0.003
755	0.023
783	0.048
810	0.045
838	0.004
866	-0.020
894	-0.113
922	-0.185
950	-0.278
963	-0.327
977	-0.417
1005	-0.770*
1019	-0.1067*
1027	-0.1354*
CURVE 27	
533	0.161
563	0.181
588	0.195
614	0.205
644	0.212
658	0.213
678	0.212
699	0.209
729	0.203
755	0.195
788	0.183
811	0.172
849	0.149
866	0.135
922	0.067
954	0.009
972	-0.027
CURVE 28	
485	0.102
513	0.117
533	0.126*
557	0.135
575	0.140
588	0.143
602	0.144*
618	0.143
644	0.139
668	0.133
699	0.123
755	0.098
781	0.083
810	0.062*
828	0.047
866	-0.004*
887	-0.042
899	-0.068
922	-0.120
940	-0.165
973	-0.248
CURVE 29	
477	0.053*
505	0.062*
533	0.067*
558	0.068*
572	0.066*
588	0.062
607	0.055
623	0.048
644	0.037
699	0.004
728	-0.016*
745	-0.029
755	-0.037
774	-0.055
811	-0.101
835	-0.145
849	-0.176
866	-0.216
883	-0.260
922	-0.363
973	-0.509
CURVE 30	
467	-0.002
477	-0.002
506	-0.005
533	-0.012*
552	-0.020
569	-0.031
588	-0.043*
614	-0.062*
644	-0.086
679	-0.118
700	-0.138
725	-0.166
755	-0.206
810	-0.318
822	-0.347
838	-0.392
866	-0.471
894	-0.553
922	-0.638
970	-0.789

* Not shown in figure.

SPECIFICATION TABLE 439. THERMAL LINEAR EXPANSION OF ASBESTOS/TEFLON COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	574	Haskins, J.F., Campbell, M.D., Hertz, J., and Percy, J.L.	1964	L	21-308	L_1	70.0 DuPont low crystallinity TFE Teflon; 30.0 Raybestos-Manhattan style 42RPD asbestos; long fiber asbestos felted sheet, parallel mat laminate; sample 0.117 x 0.117 in. x 2.0 in. from panel of 10 in. x 0.5 in. x 14 in.; sub-liquid nitrogen data corrected, obtained with vertical tube dilatometer; expansion measured in thickness direction.
2*	574	Haskins, J.F., et al.	1964	L	21-321	L_2	Similar to the above specimen; sample taken from panel 4.5 in. x 0.125 in. x 7 in.; expansion normal to thickness in the weave direction; first run.
3*	574	Haskins, J.F., et al.	1964	L	21-328	L_2	The above specimen; expansion normal to thickness in the warp direction; first run.
4*	571	Kasai, N.	1968	X	0-60		Rod-form sample, about 2 cm long, 8 mm diameter; this curve is here reported using the first given temperature (0 K) as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 439. THERMAL LINEAR EXPANSION OF ASBESTOS/TEFLON COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1*

T	$\Delta L/L_0$
21	-0.272
56	-0.256
78	-0.245
86	-0.239
96	-0.234
105	-0.228
114	-0.222
123	-0.218
132	-0.212
141	-0.206
150	-0.200
160	-0.192
169	-0.182
174	-0.177
183	-0.170
187	-0.165
195	-0.157
199	-0.151
205	-0.147
214	-0.138
219	-0.128
225	-0.122

CURVE 1 (cont.)*

T	$\Delta L/L_0$
230	-0.114
237	-0.104
242	-0.100
248	-0.089
254	-0.081
262	-0.071
269	-0.060
276	-0.049
280	-0.040
287	-0.030
292	-0.004
298	0.020
302	0.038
305	0.057
308	0.060

CURVE 2*

T	$\Delta L/L_0$
21	-0.208
51	-0.188
81	-0.169
86	-0.167
96	-0.161
109	-0.154
115	-0.150
123	-0.145
132	-0.138
140	-0.132
150	-0.126
156	-0.120
166	-0.112
171	-0.108
178	-0.102
181	-0.100
189	-0.095
194	-0.087
203	-0.081
208	-0.078
213	-0.071
221	-0.064
226	-0.059
232	-0.052
238	-0.049
244	-0.042

CURVE 2 (cont.)*

T	$\Delta L/L_0$
250	-0.037
258	-0.031
263	-0.027
269	-0.021
274	-0.018
279	-0.013
283	-0.009
288	-0.004
297	0.002
303	0.004
310	0.009
315	0.013
321	0.017

CURVE 3*

T	$\Delta L/L_0$
21	-0.376
52	-0.349
82	-0.328
88	-0.319
97	-0.309
106	-0.300
116	-0.289
123	-0.279
133	-0.265
142	-0.255
149	-0.245
159	-0.230
168	-0.218
174	-0.207
178	-0.202
185	-0.190
189	-0.182
198	-0.170
204	-0.159
209	-0.150
213	-0.143
220	-0.131
228	-0.117
233	-0.109
238	-0.098
245	-0.090
254	-0.074
259	-0.065

CURVE 3 (cont.)*

T	$\Delta L/L_0$
263	-0.059
269	-0.047
275	-0.037
279	-0.028
287	-0.014
293	0.000
297	0.010
302	0.029
308	0.038
314	0.045
319	0.050
328	0.061

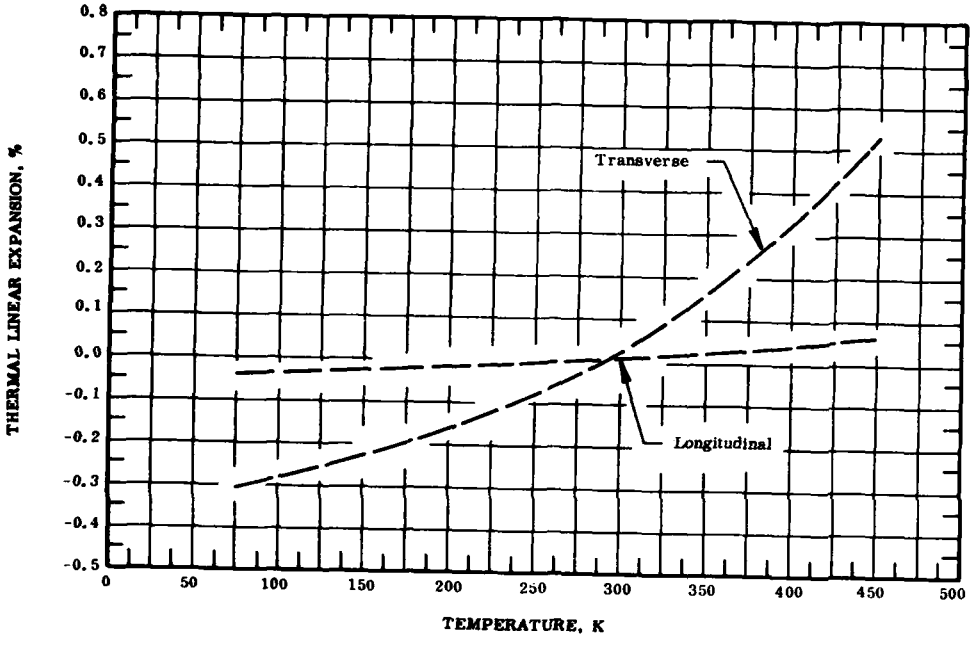
CURVE 4*,†

T	$\Delta L/L_0$
0	0.000
20	0.045
40	0.115
60	0.200

* No figure given.

† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

FIGURE AND TABLE NO. 440R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF BORON FIBER/EPOXY RESIN COMPOSITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	Transverse		Longitudinal	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
75	-0.309	10.1	-0.041	0.9
100	-0.286	10.2	-0.038	1.1
125	-0.260	10.6	-0.035	1.4
150	-0.232	11.5	-0.031	1.6
175	-0.200	12.8	-0.027	1.8
200	-0.165	14.4	-0.022	2.1
225	-0.125	16.4	-0.017	2.3
250	-0.084	18.6	-0.011	2.5
275	-0.037	21.2	-0.004	2.8
293	0.000	23.1	0.000	2.9
325	0.083	26.0	0.011	3.2
350	0.154	30.1	0.019	3.4
375	0.234	33.5	0.028	3.6
400	0.322	37.0	0.037	3.8
425	0.420	40.7	0.047	4.0
450	0.524	44.4	0.057	4.2

REMARKS

The provisional longitudinal and transverse values at temperatures above 293 K are based on the data for Boron/AVCO 5505 Composite (curves 1 and 2). The values below 293 K are obtained by extrapolating the high-temperature values according to the general trend of the data for SP-272 boron epoxy composites under various laminate orientation and experimental conditions (curves 4-23). These values are applicable to the cured Boron Fiber/Epoxy Resin Composite with fiber content of about 50 volume percent and are considered accurate to within ± 15%. These values are represented approximately by the following equations:

Transverse: $\Delta L/L_0 = -0.381 + 9.874 \times 10^{-4} T - 1.054 \times 10^{-6} T^2 + 7.432 \times 10^{-9} T^3$

Longitudinal: $\Delta L/L_0 = -0.044 + 5.874 \times 10^{-6} T + 5.431 \times 10^{-7} T^2 - 1.252 \times 10^{-10} T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 15%.

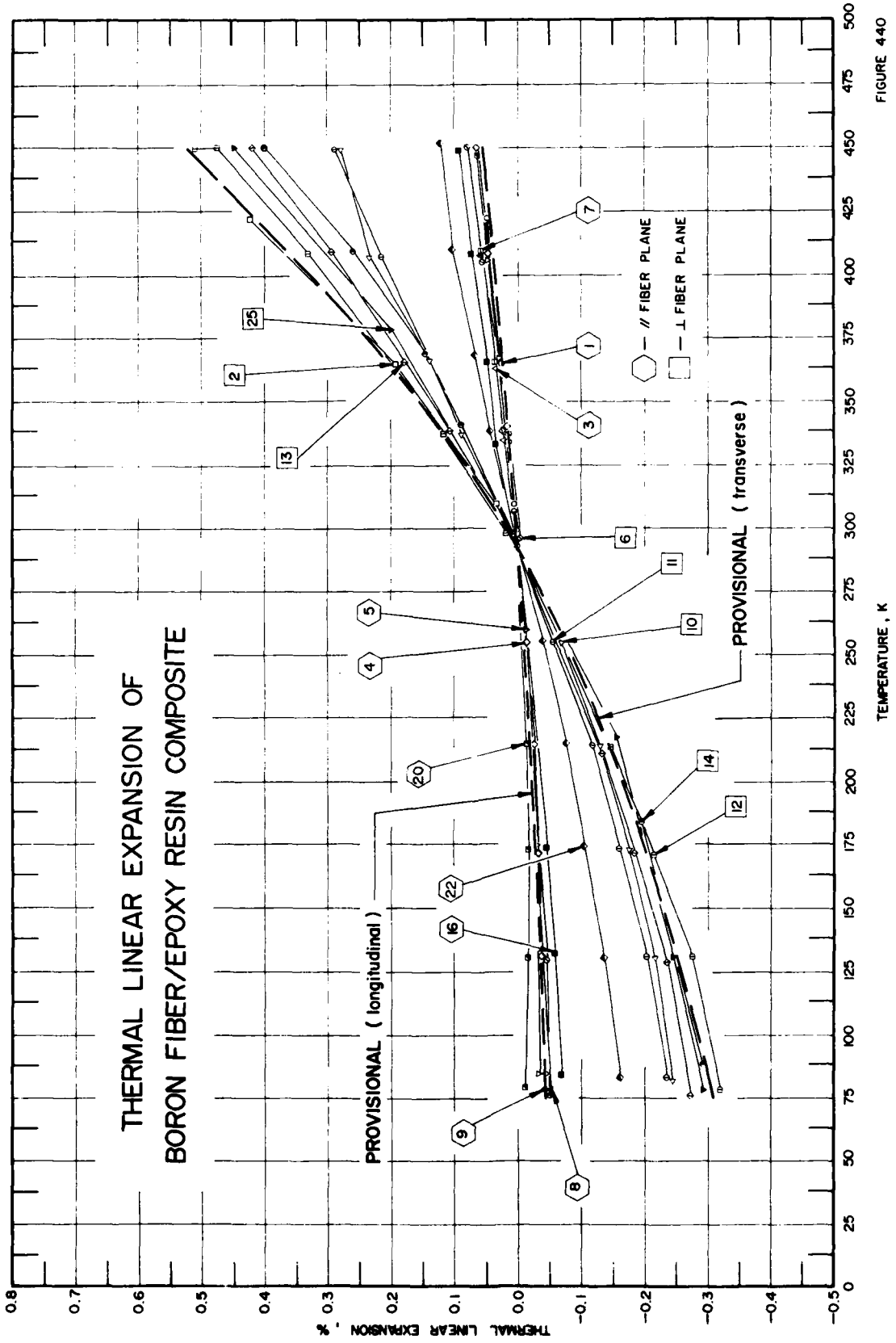

THERMAL LINEAR EXPANSION OF
BORON FIBER/EPOXY RESIN COMPOSITE
PROVISIONAL (longitudinal)
PROVISIONAL (transverse)
// FIBER PLANE
⊥ FIBER PLANE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500

FIGURE 440

SPECIFICATION TABLE 440. THERMAL LINEAR EXPANSION OF BORON FIBER/EPOXY RESIN COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1059	Nakamura, H.H. and Larsen, D.C.	1974	L	293,426	Boron/ Avco 5505	Boron/epoxy system of density 2 g cm^{-3}; fiber tensile modulus 60 x 10^6 psi; six ply of 0 deg (longitudinal) orientation; three specimens tested for each material orientation, reinforced epoxy laminates consisted of 5-7 mil diameter fiber bundles; fiber 50 volume %; autoclave process provided the final pressure and temperature cycles necessary to cure the resin; expansion in the specimen length direction measured for single 0.5 x 2 in. laminate roughly 0.050 in. thick; specimens cycled twice in air from ambient room temperature to 450 K; values based on second cycle, stable behavior.
2	1059	Nakamura, H.H. and Larsen, D.C.	1974	L	293,422	Boron/ Avco 5505	The above specimen except specimen eight ply of 90 deg (transverse) orientation; values based on second cycle, stable behavior.
3	1059	Nakamura, H.H. and Larsen, D.C.	1974	L	293,466	Boron/ Avco 5505	The above specimen except nine ply of balanced symmetric unidirectional-angle ply orientation designated $[0/45/135/0/90]_s$; plies stacked in directions (0/+45/−45/0/90/−45/+45/0); individual ply thickness 5.8 mils; values based on second cycle, stable behavior.
4	1060	Hertz, J., Christian, J.L., and Varlas, M.	1972	L	84-450	NO558	SP-272 boron epoxy composite; panel B/EP-361-5; expansion for unidirectional laminate in 0 deg direction; zero-point correction 0.002%.
5	1060	Hertz, J., et al.	1972	L	84-450	NO559	Similar to the above specimen and conditions; zero-point correction 0.003%.
6	1060	Hertz, J., et al.	1972	L	76-450	Specimen No. 670	Similar to the above specimen and conditions; panel B/EP-410-2; zero-point correction 0.002%.
7	1060	Hertz, J., et al.	1972	L	75-450	Specimen No. 667	Similar to the above specimen; last stable cycle; zero-point correction 0.007%.
8	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 723	Similar to the above specimen; water boiled for 24 hr; zero-point correction 0.002%.
9	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 719	Similar to the above specimen; specimen water boiled for 24 hr; zero-point correction 0.002%.
10	1060	Hertz, J., et al.	1972	L	82-448	NO560	Similar to the above specimen; panel B/EP-361-5; expansion for unidirectional laminate in 90 deg direction; zero-point correction 0.008%.
11	1060	Hertz, J., et al.	1972	L	82-448	NO561	Similar to the above specimen and conditions.
12	1060	Hertz, J., et al.	1972	L	76-450	Specimen No. 568	Similar to the above specimen and conditions; zero-point correction 0.015%.
13	1060	Hertz, J., et al.	1972	L	76-450	Specimen No. 569	Similar to the above specimen; panel B/EP-410-2; expansion for unidirectional lay up in 90 deg direction; last stable cycle; zero-point correction 0.025%.
14	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 721	Similar to the above specimen and conditions; specimen water boiled for 24 hr.
15	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 722	Similar to the above specimen and conditions; zero-point correction 0.001%.
16	1060	Hertz, J., et al.	1972	L	84-449	NO546	Similar to the above specimen; panel B/EP-361-5; expansion for [±45] laminate in 0 deg direction; zero-point correction 0.004%.

SPECIFICATION TABLE 440. THERMAL LINEAR EXPANSION OF BORON FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
17*	1060	Hertz, J., Christian, J. L., and Varlas, M.	1972	L	84–448	NO562	Similar to the above specimen and conditions; zero-point correction 0.004%.
18*	1060	Hertz, J., et al.	1972	L	84–450	NO564	Similar to the above specimen; expansion for [±45] laminate in 45 deg direction; zero-point correction 0.005%.
19*	1060	Hertz, J., et al.	1972	L	84–449	NO547	Similar to the above specimen and conditions; zero-point correction 0.004%.
20	1060	Hertz, J., et al.	1972	L	79–447	NO582	Similar to the above specimen; expansion for $[0_2/\pm 45]$ laminate in 0 deg direction; zero-point correction 0.002%.
21*	1060	Hertz, J., et al.	1972	L	79–447	NO583	Similar to the above specimen and conditions; zero-point correction 0.002%.
22	1060	Hertz, J., et al.	1972	L	83–452	NO584	Similar to the above specimen; expansion for $[0_2/\pm 45]_S$ in 90 deg direction; zero-point correction 0.007%.
23*	1060	Hertz, J., et al.	1972	L	83–452	NO585	Similar to the above specimen and conditions; zero-point correction 0.003%.

* Not shown in figure.

DATA TABLE 440. THERMAL LINEAR EXPANSION OF BORON FIBER/EPOXY RESIN COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
307	0.005
309	0.006
332	0.013
334	0.014*
337	0.015*
363	0.024*
365	0.025
365	0.025
422	0.046*
425	0.048
426	0.048*
CURVE 2	
293	0.000*
309	0.036
309	0.036*
310	0.038*
365	0.192
365	0.192
366	0.195*
422	0.414
422	0.414
422	0.414
CURVE 3	
293	0.000*
307	0.007*
309	0.008*
310	0.008*
334	0.020
335	0.020*
337	0.021*
363	0.034
365	0.035*
366	0.035*
CURVE 4	
84	-0.043
131	-0.038
172	-0.032
215	-0.025
255	-0.013
298	0.002
CURVE 4 (cont.)	
339	0.018
366	0.029*
408	0.047
450	0.066
CURVE 5	
84	-0.038
132	-0.035*
175	-0.030
216	-0.022*
258	-0.011
300	0.003*
339	0.017*
366	0.028
406	0.046
450	0.065*
CURVE 6	
76	-0.050
129	-0.045
172	-0.038*
213	-0.029*
255	-0.017*
296	-0.004
296	-0.001*
337	0.013
366	0.026*
405	0.051
449	0.075*
450	0.078
CURVE 7	
75	-0.045*
129	-0.040*
171	-0.034*
213	-0.025*
255	-0.013*
298	0.002*
338	0.020*
366	0.033
407	0.056
450	0.083*
CURVE 8	
78	-0.0502
130	-0.0429*
172	-0.0355*
213	-0.0253*
255	-0.0127*
296	0.0020*
296	0.0043
338	0.0220*
366	0.0373*
407	0.0591
450	0.0808*
CURVE 9	
78	-0.046
131	-0.041*
172	-0.035*
214	-0.024*
255	-0.011*
296	0.002*
337	0.020
367	0.035*
408	0.056*
450	0.079*
CURVE 10	
82	-0.243
131	-0.217
173	-0.177
214	-0.130
255	-0.070
299	0.008*
337	0.088
366	0.138
407	0.233
448	0.279
CURVE 11	
82	-0.234
131	-0.203
173	-0.160
214	-0.119
255	-0.057
299	0.008*
337	0.082*
CURVE 11 (cont.)	
366	0.138*
407	0.215
448	0.287
CURVE 12	
76	-0.319
131	-0.276
172	-0.214
214	-0.149
255	-0.071*
298	0.007*
298	0.018
339	0.115
366	0.191*
408	0.333
450	0.474
450	0.501
CURVE 13	
76	-0.272
129	-0.234
172	-0.184
211	-0.132
255	-0.060*
298	-0.002*
338	0.107
366	0.179
409	0.293
450	0.418
CURVE 14	
78	-0.292
130	-0.238*
174	-0.195
214	-0.133*
255	-0.074*
297	0.004*
341	0.089
368	0.147
409	0.259
450	0.399
CURVE 15	
78	-0.292
131	-0.246
173	-0.211*
215	-0.156
255	-0.073*
298	0.010*
339	0.103*
378	0.199
410	0.296*
450	0.447
CURVE 16	
84	-0.070
130	-0.060
173	-0.047
215	-0.032*
255	-0.014*
300	0.003*
333	0.030
367	0.046
408	0.072
449	0.094
CURVE 17*	
84	-0.072
132	-0.061
173	-0.049
216	-0.038
255	-0.020
300	0.003
338	0.026
367	0.038
410	0.057
448	0.074
CURVE 18*	
84	-0.070
130	-0.059
175	-0.048
216	-0.035
257	-0.017
299	0.005
339	0.025
366	0.041
CURVE 18 (cont.)	
409	0.062
450	0.084
CURVE 19*	
84	-0.068
133	-0.059
173	-0.047
213	-0.034
257	-0.016
299	0.005
334	0.023
366	0.044
409	0.065
449	0.091
CURVE 20	
79	-0.013
131	-0.017
173	-0.017
215	-0.017
255	-0.009*
299	0.002*
339	0.013*
367	0.023*
407	0.043*
447	0.064
CURVE 21*	
79	-0.039
131	-0.032
173	-0.029
215	-0.020
255	-0.009
299	0.002
339	0.014
366	0.025
407	0.043
447	0.064
CURVE 22	
83	-0.164
131	-0.137
174	-0.105

* Not shown in figure.

DATA TABLE 440. THERMAL LINEAR EXPANSION OF BORON FIBER/EPOXY RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 22 (cont.)	
215	-0.078
256	-0.040
299	0.006*
338	0.042
368	0.069
410	0.103
452	0.123
CURVE 23*	
83	-0.159
132	-0.135
174	-0.109
215	-0.078
255	-0.039
338	0.049
368	0.073
410	0.103
452	0.124

* Not shown in figure.

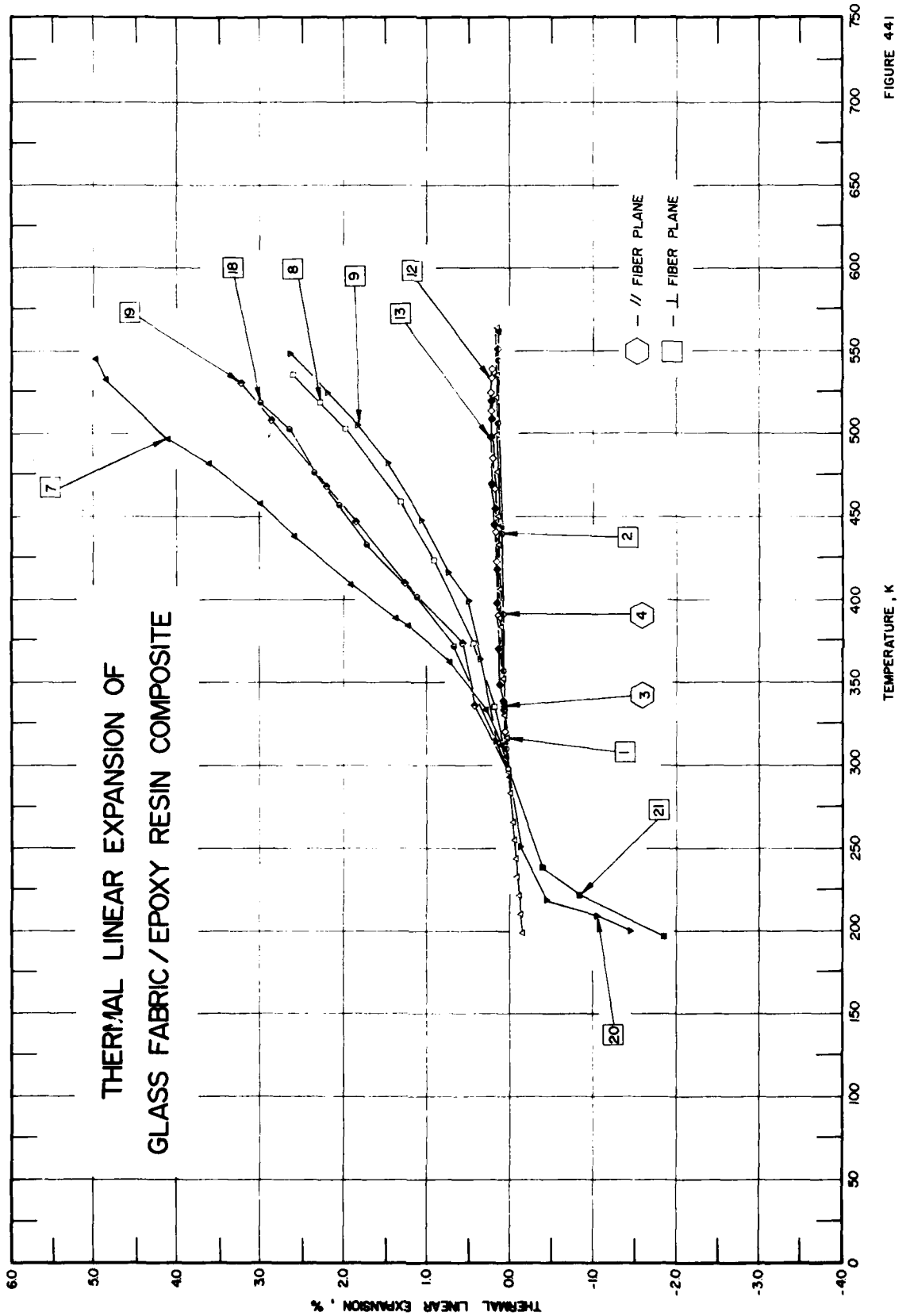

THERMAL LINEAR EXPANSION OF
GLASS FABRIC / EPOXY RESIN COMPOSITE
// FIBER PLANE
⊥ FIBER PLANE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
60
50
40
30
20
10
00
-10
-20
-30
-40
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
7
9
18
8
9
12
13
2
4
3
1
21
20

FIGURE 441

SPECIFICATION TABLE 441. THERMAL LINEAR EXPANSION OF GLASS FABRIC/EPOXY RESIN COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1053	Melonas, J.V., Covington, P.C., and Pears, C.D.	1958		199-564	X-131 Laminate	Epoxy, Shell X-131 resin and 181 glass fabric; fabricated by Brunswick-Balke-Collender Co.; nominal thickness 1/8 in.; specimen 1 in. by 7 in. long; curing process: (200 F) 366 K - 2 hr at 25 psi and (300 F) 422 K - 4 hr; first run in the transverse direction with respect to the fabric lay up; density 117 lb. ft^{-3}.
2	1053	Melonas, J.V., et al.	1958		299-544	X-131 Laminate	Second run of above specimen in transverse direction.
3	1053	Melonas, J.V., et al.	1958		199-562	X-131 Laminate	Same curing process as that of above specimen; first run in longitudinal direction with respect to the fabric lay up.
4	1053	Melonas, J.V., et al.	1958		298-551	X-131 Laminate	Second run of above specimen in longitudinal direction.
5	1053	Melonas, J.V., et al.	1958		199-562	X-131 Laminate	Same curing process as that of above specimen; first run in diagonal direction with respect to the fabric lay up.
6	1053	Melonas, J.V., et al.	1958		298-565	X-131 Laminate	Second run of above specimen in diagonal direction.
7	1053	Melonas, J.V., et al.	1958		293-545	X-131 Laminate	Same as above specimen except disk specimen with diameter 1 in. and thickness 7 3/16 in.; same curing process as that of above specimen; first run in the thickness direction with respect to the fabric lay up.
8	1053	Melonas, J.V., et al.	1958		293-536	X-131 Laminate	Second run of above specimen in thickness direction.
9	1053	Melonas, J.V., et al.	1958		293-549	X-131 Laminate	Third run of above specimen in thickness direction.
10	1053	Melonas, J.V., et al.	1958		200-293	X-131 Laminate	First run of a different specimen in thickness direction.
11	1053	Melonas, J.V., et al.	1958		202-293	X-131 Laminate	First run of a different specimen in thickness direction.
12	1053	Melonas, J.V., et al.	1958		199-539	X-131 Fluted Core Sandwich	Epoxy, shell X-131 resin and 181 glass fabric; fluted core nominal thickness 5/8 in.; flute size 0.300 in. wide, 0.350 in. thick, 0.0075 in. wall thickness; fabricated by Brunswick-Balke-Collender Co.; curing process: (200 F) 366 K - 2 hr under vacuum, post cure: (300 F) 422 K - 4 hr; first run in transverse direction with respect to the fabric lay up; density 124 lb. $ft.^{-3}$.
13	1053	Melonas, J.V., et al.	1958		293-520	X-131 Fluted Core Sandwich	Second run of above specimen in transverse direction.
14*	1053	Melonas, J.V., et al.	1958		199-536	X-131 Fluted Core Sandwich	Same curing process as that of above specimen; first run in longitudinal direction with respect to the fabric lay up.
15*	1053	Melonas, J.V., et al.	1958		293-514	X-131 Fluted Core Sandwich	Second run of above specimen in longitudinal direction.
16*	1053	Melonas, J.V., et al.	1958		199-537	X-131 Fluted Core Sandwich	Same curing process as that of above specimen; first run in longitudinal direction with respect to the fabric lay up.

* Not shown in figure.

SPECIFICATION TABLE 441. THERMAL LINEAR EXPANSION OF GLASS FABRIC/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
17*	1053	Melonas, J.V., Covington, P.C., and Pears, C.D.	1958		293-560	X-131 Fluted Core Sandwich	Second run of above specimen in diagonal direction.
18	1053	Melonas, J.V., et al.	1958		293-519	X-131 Fluted Core Sandwich	Same as above specimen except disk sample with 1 in. diameter and 5 1/4 in. thickness; same curing process as that of above specimen; first run in thickness direction with respect to the fabric lay up.
19	1053	Melonas, J.V., et al.	1958		293-531	X-131 Fluted Core Sandwich	Second run of above specimen in thickness direction.
20	1053	Melonas, J.V., et al.	1958		200-293	X-131 Fluted Core Sandwich	Same as above specimen except disk sample 5 1/8 in. thick; same curing process as that of above specimen; first run in thickness direction with respect to the fabric lay up.
21	1053	Melonas, J.V., et al.	1958		198-293	X-131 Fluted Core Sandwich	Second run of above specimen in thickness direction.

* Not shown in figure.

DATA TABLE 441. THERMAL LINEAR EXPANSION OF GLASS FABRIC/EPOXY RESIN COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
199	-0.143
210	-0.131
222	-0.112
233	-0.096
244	-0.076
255	-0.056
266	-0.037
283	-0.013
316	0.022
330	0.057
352	0.088
383	0.100
388	0.104
406	0.109
433	0.119
450	0.122
477	0.132
499	0.138
522	0.147
535	0.152
564	0.148
CURVE 2	
299	0.008*
310	0.022
332	0.053*
357	0.078
384	0.084*
440	0.098
475	0.114
506	0.127
535	0.137
544	0.136
CURVE 3	
199	-0.137*
210	-0.120*
222	-0.103*
233	-0.086*
244	-0.067*
255	-0.046*
266	-0.025*
283	-0.001*
CURVE 3 (cont.)	
310	0.027
335	0.067
359	0.091*
389	0.094*
444	0.099
477	0.108*
505	0.116*
537	0.119*
562	0.122
CURVE 4	
298	0.008*
312	0.029*
333	0.066
356	0.091*
384	0.093*
391	0.097
407	0.103*
435	0.118*
452	0.119*
478	0.128*
499	0.134*
522	0.150*
551	0.145
CURVE 5*	
199	-0.134
210	-0.120
222	-0.104
233	-0.086
244	-0.067
255	-0.050
266	-0.030
283	-0.001
309	0.028
335	0.065
356	0.085
389	0.087
443	0.090
477	0.109
507	0.127
537	0.148
562	0.153
CURVE 6	
298	0.007*
312	0.025*
333	0.059*
353	0.083*
384	0.083*
392	0.083*
408	0.086
434	0.094*
451	0.090
478	0.091
499	0.096
523	0.100
551	0.103*
565	0.089
CURVE 7	
293	0.000
303	0.030*
312	0.097
334	0.291
362	0.710
384	1.222
389	1.398
409	1.900
438	2.600
458	3.020
482	3.630
497	4.110
533	4.850
545	4.980
CURVE 8	
293	0.000*
308	0.040*
335	0.192
373	0.442
424	0.903
459	1.312
503	1.988
519	2.290
536	2.610
CURVE 9	
293	0.000*
329	0.152
364	0.334
399	0.500
416	0.728
448	1.062
482	1.470
505	1.815
525	2.180
549	2.630
CURVE 10*	
200	-0.141
220	-0.118
249	-0.086
293	0.000
CURVE 11*	
202	-0.132
208	-0.131
221	-0.117
242	-0.089
293	0.000
CURVE 12	
199	-0.153*
210	-0.138*
222	-0.121*
233	-0.105*
244	-0.088*
255	-0.070*
266	-0.052*
283	-0.021*
320	0.050
351	0.100*
390	0.130
405	0.134*
423	0.154
441	0.169
467	0.187
485	0.201
514	0.215
CURVE 12 (cont.)	
525	0.216
534	0.211
539	0.205
CURVE 13	
293	0.000*
299	0.007*
338	0.079
348	0.104
370	0.118
385	0.131*
398	0.139
418	0.141
425	0.157*
445	0.180
455	0.188
470	0.201
476	0.206*
498	0.211
509	0.206
520	0.202
CURVE 14*	
199	-0.136
210	-0.125
222	-0.111
233	-0.096
244	-0.082
255	-0.057
266	-0.030
283	-0.021
321	0.023
352	0.054
385	0.085
405	0.099
424	0.117
443	0.136
468	0.154
485	0.164
512	0.174
525	0.176
534	0.186
536	0.186
CURVE 15*	
293	0.000
300	0.006
339	0.071
353	0.081
373	0.105
388	0.112
399	0.116
420	0.128
426	0.133
446	0.151
457	0.158
467	0.171
475	0.178
497	0.187
509	0.189
514	0.227
CURVE 16*	
199	-0.153
210	-0.137
222	-0.123
233	-0.106
244	-0.092
255	-0.073
266	-0.056
283	-0.023
320	0.052
352	0.110
392	0.129
408	0.150
425	0.177
441	0.195
468	0.220
485	0.237
512	0.249
527	0.249
534	0.215
537	0.215
CURVE 17*	
293	0.000
299	0.036
333	0.067

* Not shown in figure.

DATA TABLE 441. THERMAL LINEAR EXPANSION OF GLASS FABRIC/EPOXY RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 17 (cont.)*	
344	0.086
363	0.115
378	0.132
391	0.142
420	0.159
464	0.227
479	0.221
512	0.192
522	0.163
541	0.146
554	0.129
560	0.127
CURVE 18	
293	0.000
332	0.244*
372	0.677
402	1.220
433	1.710
457	2.050
477	2.350
503	2.640
519	3.000
CURVE 19	
293	0.000
313	0.046*
336	0.410
374	0.575
410	1.262
447	1.850
468	2.200
508	2.860
531	3.220
CURVE 20	
200	-1.465
209	-1.058
219	-0.432
251	-0.119
293	0.000*
CURVE 21	
198	-1.850*
202	-1.443*
222	-0.826
238	-0.391
293	0.000*

* Not shown in figure.

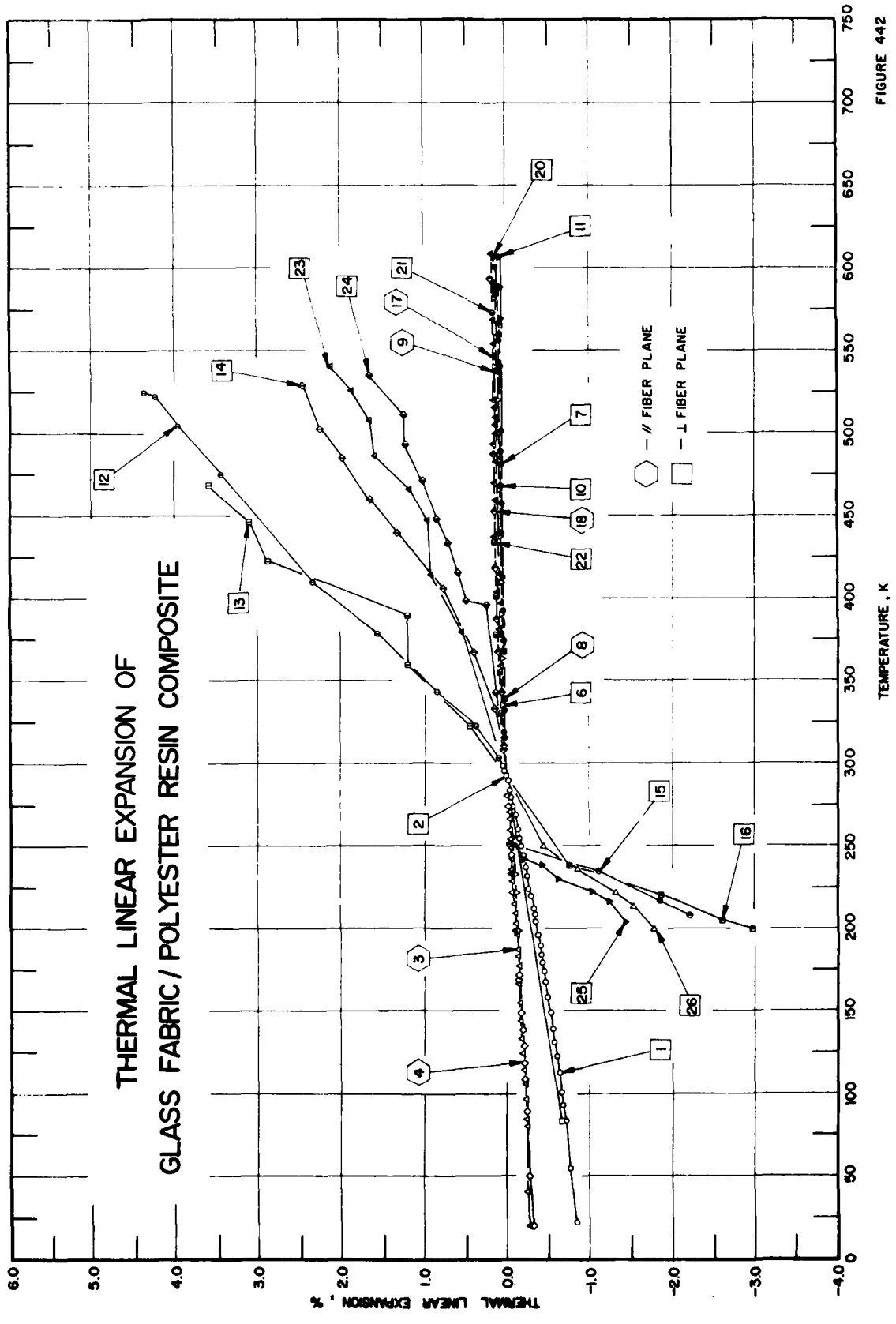

THERMAL LINEAR EXPANSION OF
GLASS FABRIC / POLYESTER RESIN COMPOSITE
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
// FIBER PLANE
⊥ FIBER PLANE
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750

FIGURE 442

SPECIFICATION TABLE 442. THERMAL LINEAR EXPANSION OF GLASS FABRIC/POLYESTER RESIN COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	574	Haskins, J.F., Campbell, M.D., Hertz, J., and Percy, J.L.	1964	L	22-298	H	62.0 "E" glass (MIL-C-9084, type VIII (181) with MIL-F-9118 finish); 38.0 Paraplex P-43 polyester resin; reinforcements consist of parallel layers of cloth; specimen 0.117 x 0.117 x 2.0 in. taken from panel of 10 in. x 0.5 in. x 14 in.; corrected sub-liquid nitrogen data; expansion measured in the thickness direction; first run.
2	574	Haskins, J.F., et al.	1964	L	83,293	H	The above specimen; immediately cycled while still in the dilatometer; fifth cycle; expansion in the thickness direction.
3	574	Haskins, J.F., et al.	1964	L	20-299	H	The above specimen; expansion measured normal to thickness in the warp direction; sub-liquid nitrogen data corrected; first run.
4	574	Haskins, J.F., et al.	1964	L	20-299	H	The above specimen; expansion measured normal to thickness in the weave direction; sub-liquid nitrogen data corrected; first run.
5*	574	Haskins, J.F., et al.	1964	L	80,293	H	The above specimen; expansion in the weave direction; fourth cycle.
6	1053	Melonas, J.V., Covington, P.C., and Pears, C.D.	1958	L	199-583	X-1068 Laminate	Tac-Polyester Vibrin X-1068 resin and 181 glass fabric; fabricated by Brunswick-Balke-Collender Co.; nominal thickness 1/8 in.; specimen 1 in. wide by 7 in. long; curing process: 366 K - 12 hr and 394 K - 3 hr under vacuum, post cure: 422 K - 1 hr, 450 K - 5 hr, and 477 K - 1 hr; first run in transverse direction with respect to the fabric lay up, density 112 lb. $ft.^{-3}$.
7	1053	Melonas, J.V., et al.	1958	L	293-601	X-1068 Laminate	Second run of above specimen in transverse direction.
8	1053	Melonas, J.V., et al.	1958	L	199-585	X-1068 Laminate	Same curing process as that of above specimen; first run in longitudinal direction with respect to the fabric lay up.
9	1053	Melonas, J.V., et al.	1958	L	293-604	X-1068 Laminate	Second run of above specimen in longitudinal direction.
10	1053	Melonas, J.V., et al.	1958	L	199-585	X-1068 Laminate	Same curing process as that of above specimen, first run in diagonal direction with respect to the fabric lay up.
11	1053	Melonas, J.V., et al.	1958	L	293-607	X-1068 Laminate	Second run of above specimen in diagonal direction.
12	1053	Melonas, J.V., et al.	1958		293-525	X-1068 Laminate	Same as above specimen except specimen 1 in. diameter and 3 15/16 in. thick; same curing process as that of above specimen; first run in thickness direction with respect to the fabric lay up.
13	1053	Melonas, J.V., et al.	1958		293-468	X-1068 Laminate	Same as above specimen except disk specimen 3 1/2 in. thick; same curing process as that of above specimen; first run in thickness direction with respect to the fabric lay up.
14	1053	Melonas, J.V., et al.	1958		293-529	X-1068 Laminate	Second run of above specimen in thickness direction.
15	1053	Melonas, J.V., et al.	1958		208-293	X-1068 Laminate	Same as above specimen except disk specimen 2 7/8 in. thick; same curing process as that of above specimen; first run in thickness direction with respect to the fabric lay up.
16	1053	Melonas, J.V., et al.	1958		200-293	X-1068 Laminate	Second run of above specimen in thickness direction.

* Not shown in figure.

SPECIFICATION TABLE 442. THERMAL LINEAR EXPANSION OF GLASS FABRIC/POLYESTER RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
17	1053	Melonas, J.V., Covington, P.C., and Pears, C.D.	1958		199-609	5016 Fluted Core Sandwich	Polyester selection-5016 resin and 181 glass fabric; flute core measured thickness 7/16 in.; flute size 0.143 in. thick, 0.375 in. wide, 0.0075 in. wall thickness; fabricated by Brunswick-Balke-Collender Co.; curing process: (250 F) 394 K - 5 hr; first run in longitudinal direction with respect to the fabric lay up; density 105 lb. $ft.^{-3}$.
18	1053	Melonas, J.V., et al.	1958		298-593	5016 Fluted Core Sandwich	Second run of above specimen in longitudinal direction.
19*	1053	Melonas, J.V., et al.	1958		199-593	5016 Fluted Core Sandwich	Same curing process as that of above specimen; first run in diagonal direction with respect to the fabric lay up.
20	1053	Melonas, J.V., et al.	1958		298-607	5016 Fluted Core Sandwich	Second run of above specimen in diagonal direction.
21	1053	Melonas, J.V., et al.	1958		199-595	5016 Fluted Core Sandwich	Same curing process as that of above specimen; first run in transverse direction with respect to the fabric lay up.
22	1053	Melonas, J.V., et al.	1958		300-609	5016 Fluted Core Sandwich	Second run of above specimen in transverse direction.
23	1053	Melonas, J.V., et al.	1958		293-540	5016 Fluted Core Sandwich	Same as above specimen except disk sample 1 in. in diameter and 5 3/8 in. in thickness; same curing process as that of above specimen; first run in thickness direction with respect to the fabric lay up.
24	1053	Melonas, J.V., et al.	1958		293-535	5016 Fluted Core Sandwich	Second run of above specimen in thickness direction.
25	1053	Melonas, J.V., et al.	1958		204-293	5016 Fluted Core Sandwich	Same as above specimen except disk sample 5 7/16 in. thick; same curing process as that of above specimen; first run in thickness direction.
26	1053	Melonas, J.V., et al.	1958		200-293	5016 Fluted Core Sandwich (Panel)	Same as above specimen except disk sample 5 1/8 in. thick; same curing process as that of above specimen; first run in thickness direction.

* Not shown in figure.

DATA TABLE 442. THERMAL LINEAR EXPANSION OF GLASS FABRIC/POLYESTER RESIN COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
22	-0.834
55	-0.770
83	-0.710
93	-0.687
101	-0.662
113	-0.630
122	-0.604
131	-0.574
139	-0.556
149	-0.527
158	-0.496
167	-0.465
174	-0.446
179	-0.423
184	-0.412
189	-0.400
196	-0.374
204	-0.350
209	-0.331
212	-0.321
220	-0.300
224	-0.277
232	-0.253
237	-0.231
244	-0.208
250	-0.180
255	-0.160
260	-0.143
269	-0.109
274	-0.089
280	-0.059
284	-0.0417
290	-0.018
296	0.0127
298	0.022
CURVE 2	
83	-0.678
293	0.000
CURVE 3	
20	-0.276
41	-0.259
80	-0.233

T	$\Delta L/L_0$
CURVE 3 (cont.)	
84	-0.228
97	-0.220
106	-0.212
114	-0.202
124	-0.194
133	-0.184
144	-0.175
155	-0.165
166	-0.153
177	-0.140
183	-0.134
187	-0.128
197	-0.118
203	-0.112
209	-0.106
215	-0.097
222	-0.089
229	-0.081
236	-0.072
242	-0.066
249	-0.057
254	-0.050
260	-0.041
267	-0.033
271	-0.026
281	-0.015
289	-0.006*
295	0.002*
299	0.008*
CURVE 4	
20	-0.302
50	-0.278
80	-0.248*
89	-0.239
98	-0.231*
108	-0.222
118	-0.211
129	-0.201
138	-0.190
149	-0.179
156	-0.169*
168	-0.157
171	-0.151
183	-0.141*

T	$\Delta L/L_0$
CURVE 4 (cont.)	
188	-0.134*
198	-0.124*
203	-0.115*
209	-0.108*
215	-0.100*
224	-0.090*
231	-0.081*
237	-0.074*
244	-0.067
249	-0.058*
256	-0.049*
260	-0.043*
268	-0.032*
274	-0.025
282	-0.013*
290	-0.004*
295	0.003*
299	0.005*
CURVE 5*	
80	-0.252
293	0.000
CURVE 6	
199	-0.149
210	-0.134*
222	-0.119
233	-0.101
244	-0.083*
255	-0.064
266	-0.045*
283	-0.015*
293	0.000*
313	0.020
335	0.029
363	0.040
390	0.053
409	0.061
437	0.073
465	0.086
487	0.091
520	0.100
541	0.110
558	0.114
583	0.127

T	$\Delta L/L_0$
CURVE 7	
293	0.000*
319	0.013
332	0.014
374	0.026
393	0.036
413	0.044
439	0.056
457	0.061
481	0.066
501	0.071
541	0.084
556	0.091
567	0.097
588	0.117
601	0.120
CURVE 8	
199	-0.146*
210	-0.135*
222	-0.121*
233	-0.101*
244	-0.084*
255	-0.068*
266	-0.051*
283	-0.016*
293	0.000*
314	0.010*
339	0.016
367	0.030
394	0.047*
411	0.054*
438	0.064*
466	0.079*
488	0.086*
520	0.087*
542	0.093
560	0.094
585	0.106
CURVE 9	
293	0.000*
320	0.017*
336	0.030*
377	0.054

T	$\Delta L/L_0$
CURVE 9 (cont.)	
397	0.064
415	0.080
440	0.097
459	0.103
482	0.109
500	0.113
505	0.123
559	0.123
566	0.126
587	0.133
604	0.141
CURVE 10	
199	-0.145*
210	-0.134*
222	-0.120*
233	-0.102*
244	-0.084*
255	-0.067*
266	-0.050*
283	-0.016*
293	0.000*
315	0.013
338	0.020*
368	0.030*
395	0.043*
413	0.046*
439	0.050*
468	0.074
488	0.074
520	0.074*
542	0.076*
559	0.076*
585	0.084*
CURVE 11	
293	0.000*
319	0.010*
333	0.013*
377	0.020*
395	0.031*
415	0.039*
441	0.042*
459	0.047*

T	$\Delta L/L_0$
CURVE 11 (cont.)	
482	0.046*
483	0.046*
542	0.056*
556	0.059*
569	0.061
588	0.069
607	0.077
CURVE 12	
293	0.000*
303	0.092
322	0.369
343	0.833
378	1.565
410	2.330
475	3.420
504	3.970
522	4.230
525	4.380
CURVE 13	
293	0.000*
323	0.423
360	1.192
390	1.190
423	2.870
446	3.100
468	3.590
CURVE 14	
293	0.000*
309	0.029
333	0.131
367	0.397
406	0.778
440	1.310
460	1.640
485	1.990
502	2.250
529	2.470

* Not shown in figure.

DATA TABLE 442. THERMAL LINEAR EXPANSION OF GLASS FABRIC/POLYESTER RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 15	
206	-2.210
217	-1.842
235	-1.105
251	-0.017
293	0.000*
CURVE 16	
200	-2.970
205	-2.600
221	-1.860
238	-0.756
293	0.000*
CURVE 17	
199	-0.109
210	-0.099*
222	-0.089*
233	-0.076
244	-0.063*
255	-0.047*
266	-0.034*
283	-0.007*
316	0.022*
332	0.045*
359	0.076
381	0.097
404	0.105
437	0.125
470	0.139
493	0.148
520	0.152
547	0.160
569	0.163
591	0.171
609	0.185
CURVE 18	
298	0.008*
311	0.031
342	0.060
368	0.098
387	0.110
419	0.116
453	0.127

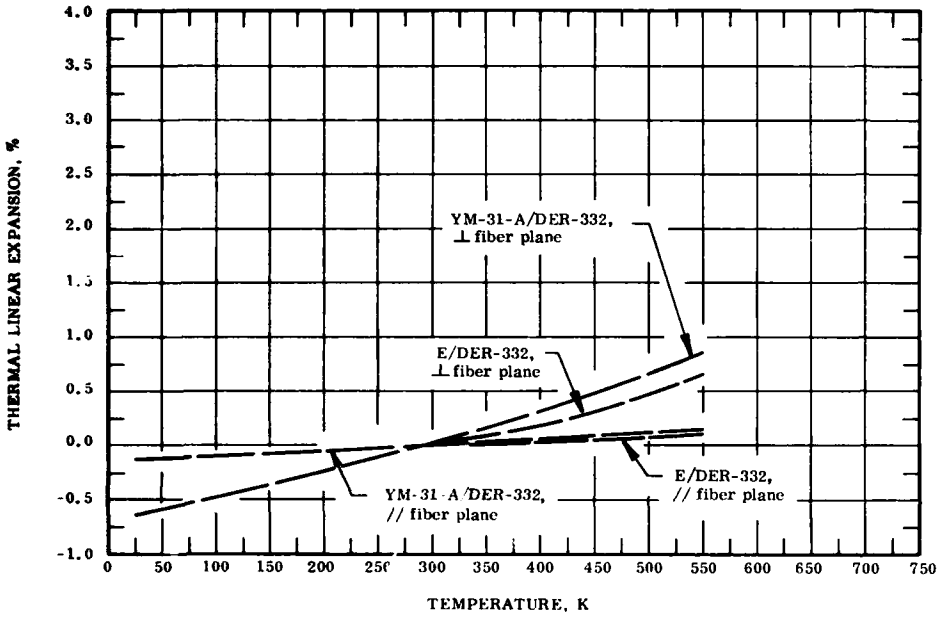
T	$\Delta L/L_0$
CURVE 18 (cont.)	
470	0.130*
487	0.134
569	0.160*
590	0.183*
593	0.186
CURVE 19*	
199	-0.120
210	-0.109
222	-0.098
233	-0.084
244	-0.070
255	-0.057
266	-0.041
283	-0.022
311	0.021
342	0.055
369	0.094
388	0.106
420	0.120
454	0.134
470	0.142
487	0.147
569	0.162
589	0.172
593	0.173
CURVE 20	
298	0.006*
314	0.024*
333	0.048*
358	0.075*
381	0.091*
405	0.094*
436	0.113*
470	0.127*
493	0.135*
520	0.138*
548	0.142*
568	0.146*
590	0.149*
607	0.152

T	$\Delta L/L_0$
CURVE 21	
199	-0.105*
210	-0.092*
222	-0.085*
233	-0.069*
244	-0.058*
255	-0.044*
266	-0.032*
283	-0.006*
309	0.023*
343	0.054*
368	0.091*
387	0.104*
420	0.114*
454	0.126*
470	0.129*
487	9.133*
573	0.156
593	0.174*
595	0.176*
CURVE 22	
300	0.012*
312	0.031*
330	0.055
355	0.082
378	0.101
402	0.108
434	0.125
470	0.139*
493	0.147*
520	0.149*
548	0.156*
569	0.162*
591	0.170*
609	0.180*
CURVE 23	
293	0.000*
380	0.548
414	0.908
448	0.964
466	1.185
486	1.600
508	1.688
526	1.870
540	2.110

T	$\Delta L/L_0$
CURVE 24	
293	0.000*
314	0.032*
342	0.110
396	0.238
398	0.500
416	0.593
433	0.702
448	0.833
471	1.013
493	1.220
511	1.236
535	1.662
CURVE 25	
204	-1.440
216	-1.235
222	-1.030
230	-0.628
238	-0.427
242	-0.205
251	-0.094
293	0.000*
CURVE 26	
200	-1.780
214	-1.522
222	-1.306
236	-0.855
250	-0.430
293	0.000*

* Not shown in figure.

FIGURE AND TABLE NO. 443R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GLASS FIBER/EPOXY RESIN COMPOSITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

YM-31-A/DER-332

	⊥ fiber plane		// fiber plane	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
25	-0.643	22.1	-0.133	3.9
30	-0.632	22.1	-0.131	4.0
40	-0.610	22.1	-0.127	4.1
50	-0.588	22.2	-0.123	4.2
60	-0.566	22.2	-0.119	4.3
70	-0.544	22.3	-0.115	4.4
80	-0.521	22.4	-0.110	4.5
90	-0.499	22.5	-0.106	4.5
100	-0.476	22.6	-0.101	4.6
150	-0.361	23.4	-0.077	5.0
200	-0.242	24.5	-0.051	5.3
250	-0.115	26.1	-0.024	5.5
273	-0.054	26.9	-0.011	5.6
293	0.000	27.7	0.000	5.7
300	0.019	28.0	0.004	5.7
350	0.164	30.2	0.033	5.8
400	0.322	32.8	0.062	5.8
450	0.494	35.8	0.091	5.8
500	0.682	39.2	0.120	5.8
550	0.886	42.9	0.148	5.8

⊥ fiber plane: $\Delta L/L_0 = -0.698 + 2.210 \times 10^{-3} T - 1.258 \times 10^{-7} T^2 + 2.447 \times 10^{-9} T^3$

// fiber plane: $\Delta L/L_0 = -0.142 + 3.642 \times 10^{-4} T + 5.567 \times 10^{-7} T^2 - 4.701 \times 10^{-10} T^3$

E/DER-332

	⊥ fiber plane		// fiber plane	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	12.7	0.000	4.4
300	0.009	13.5	0.003	4.4
350	0.089	18.7	0.025	4.5
400	0.196	23.9	0.048	4.6
500	0.486	34.2	0.094	4.7
550	0.670	39.3	0.118	4.8

⊥ fiber plane: $\Delta L/L_0 = 0.074 - 1.790 \times 10^{-3} T + 5.259 \times 10^{-6} T^2 - 6.424 \times 10^{-11} T^3$

// fiber plane: $\Delta L/L_0 = -0.118 + 3.651 \times 10^{-4} T + 1.502 \times 10^{-7} T^2 - 5.959 \times 10^{-11} T^3$

REMARKS

YM-31-A/DER-332

The provisional values in the // fiber plane direction for the cured composite with epoxy content of 20-40 weight percent and with parallel glass fiber reinforcement are derived primarily from the data of curves 19, 24, 25 and 54. It is worth noting that the thermal expansion of this composite is similar to that of YM-31-A Glass Fiber/Epon 828 Composite (curve 6). The values in the ⊥ fiber plane direction are primarily based on the data of curves 26, 52 and 53. Unlike the expansion in the direction along the fiber, the expansion along the fiber thickness is greatly affected by warpage and delamination, especially at temperatures near 475 K. Therefore, the available data in the fiber thickness direction show considerable scatter. The values are considered accurate to within ± 10% for // fiber plane direction and ± 20% for ⊥ fiber plane direction and are represented approximately by the equations below the table.

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the equations and are considered accurate to about ± 15%. The composite with cross-plied fibers has considerably higher and more irregular expansion (curves 38 and 39).

E/DER-332

The provisional values in the // fiber plane direction for the cured composite with epoxy content of about 30 weight percent and with parallel glass fiber reinforcement are derived primarily from the data of curves 30 and 31. The values in the ⊥ fiber plane direction are based on the data for the cured composite with about 20 weight percent epoxy and with parallel glass fiber reinforcement (curves 32, 33). These values are considered accurate to within ± 10% for // fiber plane direction and ± 20% for ⊥ fiber plane direction and are represented approximately by the equations below the table.

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the equations and are considered accurate to about ± 15%. The composite with cross-plied fiber shows abnormally high expansion above 475 K in the ⊥ fiber plane direction possibly due to delamination of the composite.

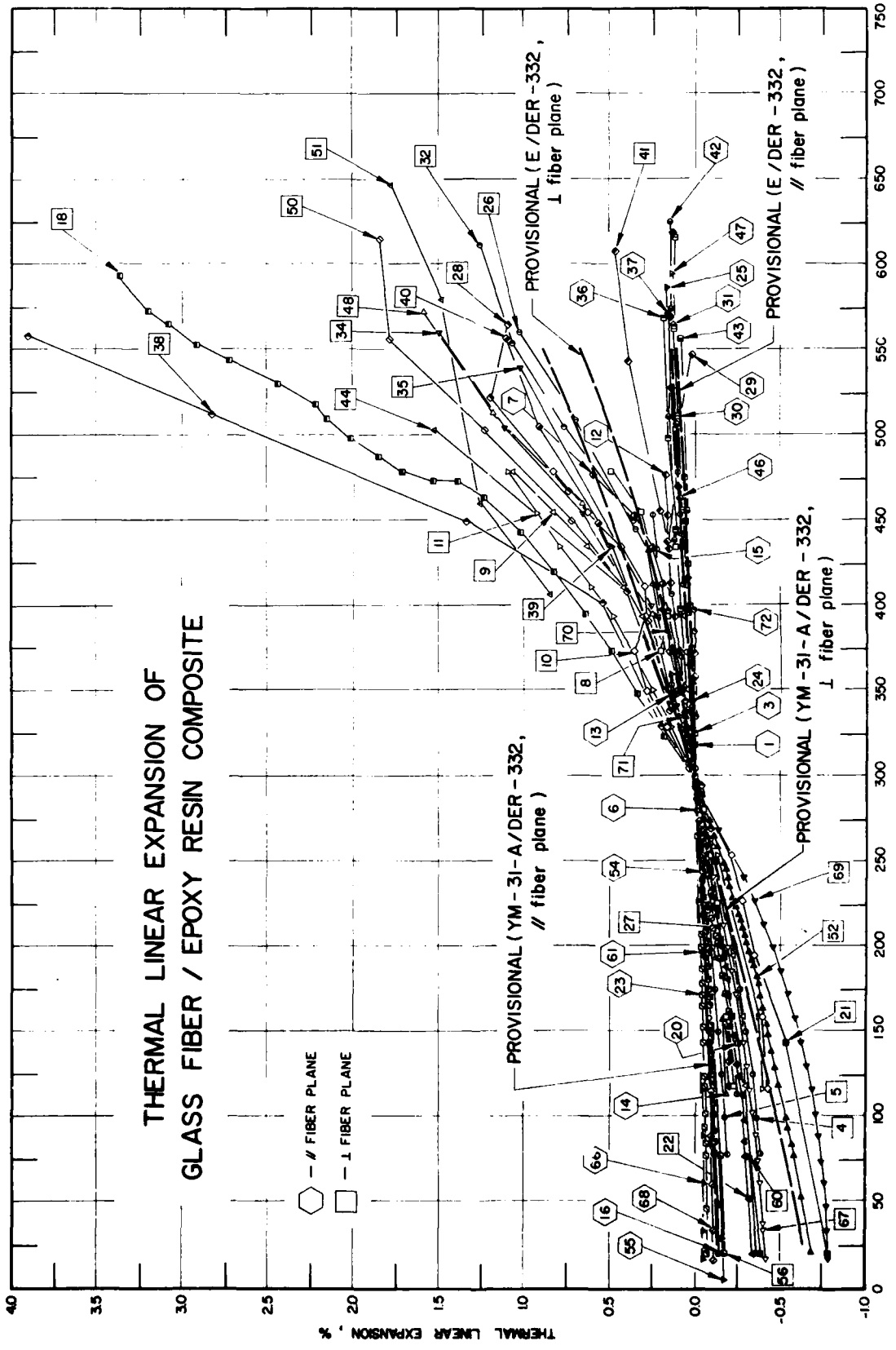

THERMAL LINEAR EXPANSION OF
GLASS FIBER / EPOXY RESIN COMPOSITE
// FIBER PLANE
⊥ FIBER PLANE
PROVISIONAL (E /DER - 332 , ⊥ fiber plane)
PROVISIONAL (E /DER - 332 , // fiber plane)
PROVISIONAL (YM - 31 - A/DER - 332, // fiber plane)
PROVISIONAL (YM - 31 - A/DER - 332, ⊥ fiber plane)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K

FIGURE 443

SPECIFICATION TABLE 443. THERMAL LINEAR EXPANSION OF GLASS FIBER/EPOXY RESIN COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1061	Gulati, S. T. and Plummer, W. A.	1972	L	153–327	LRG-18R	Longitudinal bar of quasi-isotropic composite fabricated using scotchply (3 M Co.) reinforced plastic type 1002 containing 44 volume percent of E-glass fiber in epoxy resin.
2*	1061	Gulati, S. T. and Plummer, W. A.	1972	L	153–308	LRG-41	Similar to the above specimen except transverse bar; zero-point correction is 0.009%.
3	1062, 1063	Kritsuk, A. A.	1972	L	78–476	GRP	Glass reinforced plastic cut with diamond disc from sheets prepared by "wet" winding on a metal mandrel and cured under ~10 kg f cm^{-2} pressure; epoxy-amine formulation (ED-6 epoxy resin hardened with triethanolamine titanate) used as binder and nonalkaline NS/6 glass fiber used as filler; epoxy content 19.5 weight percent; measurements along the reinforcement; zero-point correction -0.005%.
4	1062, 1063	Kritsuk, A. A.	1972	L	78–370		Similar to the above specimen except measurements along transverse direction; zero-point correction is -0.018%.
5	1062, 1063	Kritsuk, A. A.	1972	L	78–420		Similar to the above specimen except measurements for glass reinforced plastic with 1:1 structure; zero-point correction is -0.003%.
6	573	General Electric Co.	1964	V	122–478		Glass fibers ("E" glass) from Pittsburgh Glass Co. placed in shell Epon 828 solid fibers placed longitudinally; specimen cured 2 hr at 366 K, 4 hr at 394 K, and 6 hr at 422 K; soaked 30 min at 116 K and tested with heating at 0.6 deg/min; expansion measured parallel to fibers; zero-point correction is -0.097%.
7	573	General Electric Co.	1964	V	133–477		Similar to the above specimen except hollow glass fibers; zero-point correction is -0.197%.
8	573	General Electric Co.	1964	V	118–478		Similar to the above specimen except expansion measured transverse to solid fibers; zero-point correction is -0.220%.
9	573	General Electric Co.	1964	V	118–478		The above specimen; second run; zero-point correction is -0.295%.
10	573	General Electric Co.	1964	V	117–478		Similar to the above specimen except hollow glass fibers; zero-point correction is -0.428%.
11	573	General Electric Co.	1964	V	117–478		Similar to the above specimen; second cycle; zero-point correction is -0.394%.
12	573	General Electric Co.	1964	V	118–477		Similar to the above specimen except solid fibers placed in 90 deg mesh oriented diagonally with respect to the expansion direction; zero-point correction is -0.175%.
13	573	General Electric Co.	1964	V	118–453		Similar to the above specimen except hollow glass fibers; zero-point correction is -0.217%.
14	573	General Electric Co.	1964	V	114–478		Similar to the above specimen except solid fibers placed in 90 deg mesh oriented diagonally with respect to the expansion direction; zero-point correction is -0.175%.
15	573	General Electric Co.	1964	V	114–454		Similar to the above specimen except hollow glass fibers; zero-point correction is -0.245%.
16*	573	General Electric Co.	1964	V	117–478		Similar to the above specimen except solid fibers placed in 60 deg mesh oriented diagonally with respect to the expansion direction; zero-point correction is -0.261%.

* Not shown in figure.

SPECIFICATION TABLE 443. THERMAL LINEAR EXPANSION OF GLASS FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
17[a]	573	General Electric Co.	1964	V	117-478		Similar to the above specimen except hollow glass fibers; zero-point correction is -0.337%.
18	1064	Lagedrost, J. F., Fabish, T.J., Eldridge, E.A., Deem, H.W., Krause, H.H., and Vaughan, D.A.	1968	L	293-593		Composite consisted of anhydride cured (nadic methyl anhydride 38.7 weight percent) epoxy novolac (Dow Chemical Co. DEN-438, 45.6 weight percent) and chopped (1/32 in. hammer-milled) 15 weight percent fiber glass; density 1.33 g cm^{-3} at 293 K and 1.20 g cm^{-3} at 573 K; measurements in argon atmosphere; zero-point correction is 0.02%.
19	1057	Campbell, M.D., Haskins, J.F., O'Barr, G.L., and Hertz, J.	1966	L	20-297	Specimen D	Owens-Corning high modulus YM-31-A glass fiber roving with HTS finish, and 20 weight percent Dow Chemical DER-332 epoxy resin cured with acid anhydride, unidirectional, parallel fibers; flat molding; average density 2.01 g cm^{-3}; zero-point correction is 0.002%.
20	1057	Campbell, M.D., et al.	1966	L	20-297	Specimen E	Simulated helical filament wound fiber-reinforced epoxy; 20 weight percent (36.2 weight percent average of two panels) Dow Chemical DER-332 epoxy resin cured with acid anhydride; Owens-Corning YM-31-A glass fiber roving with HTS finish; alternat layers of roving cross plied at angles of 57 and 303 deg from horizontal axis; density 1.94 g cm^{-3}; expansion measured normal to the thickness direction; normal to 57 deg ply; zero-point correction is -0.007%.
21	1057	Campbell, M.D., et al.	1966	L	20-297	Specimen E	Similar to the above specimen; expansion measured along the thickness direction; parallel to 57 deg ply; zero-point correction is -0.003%.
22	1058	Campbell, M.D., O'Barr, G.L., Haskins, J.F., and Hertz, J.	1965	L	20-296		Composite system from CTL, division of Studbaker; S-994 glass roving; E-787 epoxy resin (30 weight percent) from U.S. Polymeric; specimen unidirectional molding of HTS finish; glass roving and resin pressed; heated to 366 K and held for 1/2 hr; raised temperature to 427 K and held for 1.5 hr; average of runs on two similar specimens; measurements along thickness direction; zero-point correction is 0.005%.
23	1058	Campbell, M.D., et al.	1965	L	20-296		The above specimen; measurements parallel to fibers; zero-point correction is 0.001%.
24	1065	Pears, C.D., Engelke, W.T., and Thornburgh, J.D.	1964	L	282-619	Material C1	Composite (density 1.91 g cm^{-3}, void content 5-10 volume percent) from Raytheon Corp. containing 40 weight percent DER-332 epoxy cured with methyl nadic anhydride 80 parts per 100 gr. resin and DMP 30, 2 parts per 100 parts of resin; Owens-Corning high modulus YM31-A glass fiber roving; HTS finish; unidirectional parallel to surface lay up; cured at 200 psi; heated at 366 K for 2 hr and 394 K for 2 hr; heating cycle; measurements parallel to the fiber direction; zero-point correction is 0.003%.
25	1065	Pears, C.D., et al.	1964	L	583-296	Material C1	The above specimen; cooling cycle; zero-point correction is 0.224%.
26	1065	Pears, C.D., et al.	1964	L	261-561	Material C1	The above specimen; expansion measured in the thickness direction; heating cycle; specimen continued to expand on cooling; zero-point correction is 0.05%.
27	1065	Pears, C.D., et al.	1964	L	262-207	Material C1	The above specimen; expansion measured in the thickness direction; cooling cycle; zero-point correction is -0.01%.
28	1065	Pears, C.D., et al.	1964	L	260-565	Material C1	The above specimen; expansion measured in the perpendicular to the reinforcement direction; heating cycle; zero-point correction is -0.006%.
29	1065	Pears, C.D., et al.	1964	L	548-293	Material C1	The above specimen; expansion measured in the perpendicular to the reinforcement direction; cooling cycle; zero-point correction is 1.748%.

SPECIFICATION TABLE 443. THERMAL LINEAR EXPANSION OF GLASS FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
30	1065	Pears, C.D., Engelke, W.T., and Thornburgh, J.D.	1964	L	283-617	Material C2	Composite (density 1.85 g cm^{-3}, void content 5 volume percent) from Raytheon Corp. containing 30 weight percent (28.23 weight percent after cure) Dow Chemical DER 332 epoxy bisphenol A cured with nadic anhydride 80 parts per 100 gr. resin and DMP-30, 30 parts per 100 parts of resin; Owens-Corning "E" glass fiber roving; HTS finish; 40 layers parallel to surface lay up; cured at 200 psi, 2 hr at 366 K, 2 hr at 394 K; heating cycle; expansion measured in the direction parallel to reinforcement.
31	1065	Pears, C.D., et al.	1964	L	564-296	Material C2	The above specimen; measurements in the direction parallel to reinforcement; cooling cycle; zero-point correction is 0.119%.
32	1065	Pears, C.D., et al.	1964	L	264-612	Material C2	The above specimen; expansion measured in the thickness direction; heating cycle; zero-point correction is -0.004%.
33*	1065	Pears, C.D., et al.	1964	L	254-226	Material C2	The above specimen; expansion measured in the thickness direction; cooling cycle.
34	1065	Pears, C.D., et al.	1964	L	263-560	Material C2	The above specimen; expansion measured in the direction perpendicular to the reinforcement; heating cycle; zero-point correction is 0.006%.
35	1065	Pears, C.D., et al.	1964	L	540-294	Material C2	The above specimen; expansion measured in the direction perpendicular to the reinforcement; cooling cycle; zero-point correction is 1.423%.
36	1065	Pears, C.D., et al.	1964	L	222-569	Specimen C-3	Composite (density 1.94 g cm^{-3}, void content 5-10 volume percent) from Raytheon Corp., containing 40 weight percent (32.15 weight percent after cure) Dow Chemical DER 332 epoxy bisphenol cured with methyl nadic anhydride, 80 parts per 100 gms of resin, and DMP 30, 2 parts per 100 gms of resin; Owens-Corning high modulus YM-31-A glass fiber roving; HTS finish; 40 layers cross plied parallel and 66 deg from the horizontal axis; cured at 200 psi; 2 hr at 366 K, and 2 hr at 394 K, heating cycle; expansion measured in the direction of material.
37	1065	Pears, C.D., et al.	1964	L	571-304	Specimen C-3	The above specimen; expansion measured in the direction of material; cooling cycle; zero-point correction is 0.312%.
38	1065	Pears, C.D., et al.	1964	L	270-558	Specimen C-3	The above specimen; expansion measured in the thickness direction; heating cycle; zero-point correction is 0.028%.
39	1065	Pears, C.D., et al.	1964	L	435-294	Material C-3	The above specimen; expansion measured in the thickness direction; cooling cycle; zero-point correction is -0.321%.
40	1065	Pears, C.D., et al.	1964	L	281-557	Material C-3	The above specimen; expansion measured in the direction perpendicular to fiber orientation; heating cycle; zero-point correction is -0.014%.
41	1065	Pears, C.D., et al.	1964	L	609-291	Material C-3	The above specimen; expansion measured in the direction perpendicular to fiber orientation; cooling cycle; zero-point correction is 1.557%.
42	1065	Pears, C.D., et al.	1964	L	270-626	Material C-.	Composite (density 2.10 g cm^{-3}, void content 5 volume percent) from Raytheon Corp., containing 20 weight percent (17.7 weight percent after cure) Dow Chemical DER-332 (bisphenol) epoxy cured with methyl nadic anhydride 80 parts per 100 gms resin and DMP-30, 2 parts per 100 gms resin; Owens-Corning "E" glass fiber roving, HTS finish; lay ups parallel to surface, 40 layers cross plied; cured at 200 psi; 2 hr at 360 K, 2 hr at 394 K; expansion measured in the direction of fiber; heating cycle; zero-point correction is 0.003%.

* Not shown in figure.

SPECIFICATION TABLE 443. THERMAL LINEAR EXPANSION OF GLASS FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
43	1065	Pears, C.D., Engelke, W.T., and Thornburgh, J.D.	1964	L	557-295	Material C-4	The above specimen; expansion measured in the direction of fiber; cooling cycle; zero-point correction is 0.064%.
44	1065	Pears, C.D., et al.	1964	L	264-503	Material C-4	The above specimen; expansion measured in the thickness direction; heating cycle.
45*	1065	Pears, C.D., et al.	1964	L	234-223	Material C-4	The above specimen; expansion measured in the thickness direction; cooling cycle; zero-point correction is 0.036%.
46	1065	Pears, C.D., et al.	1964	L	274-615	Material C-5	Composite (density 2.06 g cm^{-3}, void content 5 volume percent) from Raytheon Corp., containing 20 weight percent (21.06 weight percent after cure) Dow Chemical DEN-438 epoxy cured as above; Owens-Corning "E" glass fiber roving 20 end, HTS finish, unidirectional 40 layers parallel to surface; cured at 200 psi; 2 hr at 366 K, 2 hr at 394 K; expansion measured parallel to the reinforcement direction; heating cycle.
47	1065	Pears, C.D., et al.	1964	L	595-349	Material C-5	The above specimen; expansion measured parallel to the reinforcement direction; cooling cycle; zero-point correction is 0.096%.
48	1065	Pears, C.D., et al.	1964	L	258-572	Material C-5	The above specimen; measurement in the thickness direction; heating cycle; zero-point correction is 0.010%.
49*	1065	Pears, C.D., et al.	1964	L	255-222	Material C-5	The above specimen; measurement in the thickness direction; cooling cycle.
50	1065	Pears, C.D., et al.	1964	L	288-615	Material C-5	The above specimen; measurement in the perpendicular to reinforcement; heating cycle.
51	1065	Pears, C.D., et al.	1964	L	648-406	Material C-5	The above specimen; measurement in the perpendicular to reinforcement; cooling cycle; zero-point correction is 3.028%.
52	574	Haskins, J.F., Campbell, M.D., Hertz, J., and Percy, J.L.	1964	L	21-298		Owens-Corning high modulus YM-31-A glass fiber roving (80 weight percent) with HTS finish; Dow Chemical DER-332 epoxy resin cured with acid anhydride; unidirectional, parallel fibers, flat molding; specimen 0.117 x 0.117 x 20 in. stacked and loaded by series of 0.5 in. wide pieces in the thickness direction from the panel; zero-point correction is 0.003%.
53*	574	Haskins, J.F., et al.	1964	L	77, 298		The above specimen; immediately cycled while still in the dilatometer; third cycle; expansion measured in the thickness direction; zero-point correction is 0.005%.
54	574	Haskins, J.F., et al.	1964	L	20-298		The above specimen; expansion measured parallel to reinforcement; first run; using vertical dilatometer in subliquid hydrogen temperature and data corrected; zero-point correction is 0.003%.
55	560	Brechna, H. and Haldemann, W.	1965	L	5-301	S994/HTS	S994/HTS glass roving with 19 weight percent Union Carbide ERL 2256/MPDA epoxy resin; average density 2.1 g cm^{-3}.
56	1066, 1067	Toth, L.W., Boller, T.J., Butcher, I.R., Kariotis, A.H., and Yoder, F.D.	1965	L	20-297	BFW	Reinforced plastic using S/HTS glass from U.S. Polymeric Chem. Inc.; 20-end roving filament wound in bidirectional (0-90 deg, 1/1 dispersion) orientation; preimpregnated with 19.10% E-787 epoxy system; expansion measured normal to reinforcement.
57*	1066, 1067	Toth, L.W., et al.	1965	L	20-297	BFW	The above specimen; second run.

* Not shown in figure.

SPECIFICATION TABLE 443. THERMAL LINEAR EXPANSION OF GLASS FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
58*	1066, 1067	Toth, L.W., Boller, T.J., Butcher, I.R., Kariotis, A.H., and Yoder, F.D.	1965	L	20-297	BFW	Similar to the above specimen except expansion measured parallel to the reinforcement.
59*	1066, 1067	Toth, L.W., et al.	1965	L	20-297	BFW	The above specimen; second run.
60	1066, 1067	Toth, L.W., et al.	1965	L	20-297	UFW	Similar to the above specimen except filament wound in unidirectional orientation; resin content 18.03%; expansion measured normal to reinforcement.
61	1066, 1067	Toth, L.W., et al.	1965	L	20-297	UFW	The above specimen except expansion measured parallel to reinforcement.
62*	1067	Toth, L.W., Boller, T.J., Butcher, I.R., Kariotis, A.H., and Yoder, F.D.	1966	L	77-297	S Glass-DER 332/BF_3	Reinforced plastic consisted of 17.4% DER-332 epoxy resin; BF_3 curing agent and 20-end S/HTS glass roving; expansion measured parallel to reinforcement.
63*	1067	Toth, L.W., et al.	1966	L	77-297	S Glass-DER 332/BF_3	The above specimen; expansion measured normal to reinforcement.
64*	1067	Toth, L.W., et al.	1966	L	77-297	S Glass-DER 332/DEH 50	Reinforced plastic, consisted of 19% DER-332 epoxy resin, DEH 50 curing agent and 20-end S/HTS glass roving; expansion measured parallel to reinforcement.
65*	1067	Toth, L.W., et al.	1966	L	77-297	S Glass-DER 332/DEH 50	The above specimen; expansion measured normal to reinforcement.
66	1068	Soffer, L.M. and Molho, R.	1968	L	22-294	Resin 2 Laminate	Resin 2 laminates were prepared from Epon 828/DSA/1040/BDMA resin system by in-process winding (S-901 glass filament) on a 6 x 8 in. flat mandrel, after cure the panels were cut and sanded into rectangular beam specimen, three specimens prepared for testing in the longitudinal (parallel to the filament orientation) direction; resin content 17.1 weight percent.
67	1068	Soffer, L.M. and Molho, R.	1968	L	17-294	Resin 2 Laminate	Similar to the above specimen except three specimens were prepared for testing in the transverse (normal to the filament orientation) direction; resin content 14.4 weight percent.
68	1068	Soffer, L.M. and Molho, R.	1968	L	17-294	Resin 4A Laminate	Resin 4A laminates were prepared from Epon 828/Epon 871/L-100/MOCA resin system by applying on the mandrel alternate layers of roving (S-901 glass filament) and coating of resin applied by brush; a heat gun trained on the mandrel maintained a temperature of 338 K; after cure the panels were cut and sanded into rectangular beam specimens, three specimens prepared for testing in the longitudinal (parallel to the filament orientation) direction; resin content 37.7 weight percent.
69	1068	Soffer, L.N. and Molho, R.	1968	L	17-294	Resin 4A Laminate	Similar to the above specimen except three specimens were prepared for testing in the transverse (normal to the fiber orientation) direction; resin content 30.4 weight percent.
70	1069	Kalnin, I.L.	1974	L	293-411	S-glass	UD (unidirectional) composite made from prepegged S-glass (Ferro, S-1014) year bundles by the "leaky" pressure molding technique; fiber content 69 volume percent; void content 2.5% ignored in the calculation; specimen length 50 mm; cycled 2-3 times from room temperature to 423 K to relieve non-equilibrium thermal stresses; measurements in transverse direction; heating cycle; zero-point correction is 0.006%.

* Not shown in figure.

SPECIFICATION TABLE 443. THERMAL LINEAR EXPANSION OF GLASS FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
71	1069	Kalnin, I. L.	1974	L	411-293	S-glass	The above specimen; cooling cycle; zero-point correction is 0.006%.
72	1069	Kalnin, I. L.	1974	L	293-399	S-glass	The above specimen; measurements in the axial direction; heating cycle; zero-point correction is 0.001%.
73*	1069	Kalnin, I. L.	1974	L	399-293	S-glass	The above specimen; cooling cycle; zero-point correction is 0.001%.

* Not shown in figure.

DATA TABLE 443. THERMAL LINEAR EXPANSION OF GLASS FIBER/EPOXY RESIN COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
153	-0.202
162	-0.189
172	-0.170
183	-0.159
193	-0.147
202	-0.131
212	-0.117*
222	-0.103*
232	-0.089
242	-0.075
253	-0.058*
263	-0.041
287	-0.011*
293	0.000*
298	0.002*
308	0.007*
318	0.010
327	0.015*
CURVE 2*	
153	-0.204
162	-0.192
173	-0.178
183	-0.162
193	-0.144
202	-0.133
213	-0.118
222	-0.106
232	-0.090
242	-0.073
252	-0.056
262	-0.043
273	-0.020
287	-0.003
293	0.000
308	0.021
CURVE 3	
78	-0.112*
100	-0.105*
125	-0.092
150	-0.083
175	-0.073
200	-0.057
225	-0.043*
250	-0.027*
275	-0.011*
293	0.000*
300	0.002
325	0.010
350	0.020*
375	0.029
400	0.038
425	0.049
450	0.058
476	0.067
CURVE 4	
78	-0.379
100	-0.359
125	-0.330
150	-0.296
175	-0.256
200	-0.215
225	-0.167*
250	-0.113
275	-0.048
293	0.000*
300	0.012*
320	0.067
325	0.073
330	0.076
350	0.078
370	0.079
CURVE 5	
78	-0.183
100	-0.169
125	-0.150
150	-0.132
175	-0.112
200	-0.091
225	-0.067
250	-0.044*
275	-0.017*
293	0.000*
300	0.012*
325	0.027*
350	0.041*
375	0.050*
400	0.060*
420	0.067*
CURVE 6	
122	-0.097
158	-0.076
194	-0.056
225	-0.042
253	-0.025
280	-0.006
305	0.005
328	0.023
351	0.044
373	0.053
394	0.063
413	0.073
435	0.082
454	0.093
478	0.103
CURVE 7	
133	-0.197
158	-0.186*
194	-0.160*
225	-0.126*
258	-0.085*
280	-0.016*
305	0.015*
328	0.063
351	0.103
373	0.153
394	0.173*
413	0.194
435	0.204
453	0.213
477	0.235
CURVE 8	
118	-0.220
159	-0.176
195	-0.185
226	-0.127
254	-0.080
281	-0.041
308	0.048
329	0.093
351	0.168
373	0.202
394	0.166
413	0.060
435	0.121
455	0.324
478	0.495
CURVE 9	
118	-0.295
159	-0.277
195	-0.215
226	-0.161
254	-0.089*
280	-0.022
308	0.025
329	0.093*
351	0.153*
373	0.218*
394	0.307
411	0.424
435	0.638
455	0.833
478	1.062
CURVE 10	
117	-0.428
158	-0.396
195	-0.344
227	-0.271
254	-0.209
280	-0.049*
305	0.045
329	0.174
350	0.283
373	0.356
394	0.294
412	0.294
435	0.436
455	0.637
478	0.834
CURVE 11	
117	-0.394
158	-0.377
195	-0.356*
227	-0.274*
254	-0.128
280	-0.047*
305	0.042*
329	0.150
351	0.251
373	0.348*
394	0.484
412	0.610
435	0.795
454	0.934
478	1.092
CURVE 12	
118	-0.194
158	-0.163*
194	-0.135*
224	-0.094
252	-0.054
280	-0.016*
305	0.014*
328	0.045*
349	0.076*
373	0.094
394	0.124
414	0.144
434	0.154
453	0.165
477	0.176
CURVE 13	
118	-0.217*
158	-0.167*
193	-0.116
224	-0.097*
252	-0.077*
280	-0.027*
305	0.024*
328	0.084*
349	0.144
373	0.202*
392	0.225*
413	0.253
433	0.275
453	0.286*
CURVE 14	
114	-0.175
158	-0.154
194	-0.114*
224	-0.095*
253	-0.055*
280	-0.015*
306	0.014*
329	0.045*
352	0.074
373	0.093*
394	0.113*
413	0.142*
435	0.163*
454	0.174*
478	0.182*
CURVE 15	
114	-0.245
158	-0.224*
194	-0.163*
224	-0.124*
252	-0.085*
280	-0.026*
305	0.025*
330	0.085*
353	0.145
373	0.203*
393	0.226*
412	0.236
434	0.244
454	0.253

* Not shown in figure.

DATA TABLE 443. THERMAL LINEAR EXPANSION OF GLASS FIBER/EPOXY RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 16	
117	-0.261
158	-0.234
195	-0.170*
224	-0.121*
251	-0.063*
280	-0.022*
304	0.018*
330	0.066*
351	0.119*
373	0.159*
395	0.128*
414	0.105
435	0.177
454	0.307
478	0.423
CURVE 17	
117	-0.337*
158	-0.292*
195	-0.221*
224	-0.197
251	-0.113*
280	-0.038*
304	0.032*
330	0.127
352	0.213
374	0.293
393	0.372
412	0.480
434	0.592
452	0.691
478	0.791
CURVE 18	
293	0.00*
299	0.02*
323	0.18
349	0.34
373	0.49
395	0.64
420	0.83
443	1.02
463	1.24
473	1.38
473	1.53
479	1.71

T	$\Delta L/L_0$
CURVE 18 (cont.)	
487	1.85
499	2.01
510	2.15
518	2.22
530	2.43
544	2.72
553	2.91
565	3.07
573	3.19
593	3.36
CURVE 19	
20	-0.132
144	-0.087
297	0.005
CURVE 20	
20	-0.376
144	-0.250
297	0.007*
CURVE 21	
20	-0.777
144	-0.537
297	0.003*
CURVE 22	
20	-0.339
52	-0.315
76	-0.296
86	-0.287
98	-0.280
113	-0.262
124	-0.249
131	-0.243
148	-0.222
159	-0.218
171	-0.194
181	-0.182
188	-0.171
194	-0.163
200	-0.153
205	-0.144
212	-0.131

T	$\Delta L/L_0$
CURVE 22 (cont.)	
219	-0.123
222	-0.116
229	-0.107
235	-0.096
245	-0.080
255	-0.068
260	-0.056
267	-0.044
279	-0.026*
285	-0.014
289	-0.005
292	-0.002
296	0.005*
CURVE 23	
20	-0.068
46	-0.064
77	-0.058
77	-0.057*
85	-0.055
94	-0.053
102	-0.052
118	-0.049
123	-0.048
143	-0.043
152	-0.041
165	-0.037
171	-0.035
179	-0.034
187	-0.031
200	-0.029
207	-0.029
219	-0.025*
228	-0.023*
234	-0.021*
240	-0.019*
251	-0.014*
260	-0.011*
265	-0.009
269	-0.007*
275	-0.006*
281	-0.004*
293	0.000*
298	0.001*

T	$\Delta L/L_0$
CURVE 24	
282	-0.008
297	0.001*
297	0.003*
344	0.026
398	0.067
470	0.102
528	0.141
570	0.149
619	0.139
CURVE 25	
583	0.176
415	0.067
354	0.021
296	0.001*
CURVE 26	
261	-0.040*
295	0.001*
297	0.022*
337	0.071
407	0.141
445	0.350
509	0.700
561	1.039
CURVE 27	
262	-0.030*
217	-0.092
211	-0.107
207	-0.124
CURVE 28	
260	-0.068*
295	0.013*
339	0.152
409	0.401
467	0.742
522	1.203
565	1.092
CURVE 29	
548	0.026

T	$\Delta L/L_0$
CURVE 29 (cont.)	
438	0.163
358	0.012
293	0.000*
CURVE 30	
283	-0.009*
294	0.001
340	0.026
396	0.055
456	0.080
511	0.108
563	0.130
617	0.130
CURVE 31	
564	0.128
416	0.052
296	0.001*
CURVE 32	
264	-0.080
292	-0.011*
293	0.000*
344	0.066
396	0.166
450	0.368
505	0.762
554	1.073
612	1.265
CURVE 33*	
254	-0.056
226	-0.113
CURVE 34	
263	-0.061*
296	0.006*
341	0.118
394	0.251*
454	0.653
504	1.114
560	1.495

T	$\Delta L/L_0$
CURVE 35	
540	1.024
400	0.258
294	0.000*
CURVE 36	
222	-0.065
292	0.000*
350	0.044*
398	0.083
445	0.120
499	0.168
569	0.184
CURVE 37	
571	0.162
442	0.090
365	0.048
304	0.007*
CURVE 38	
270	-0.089
295	-0.029
295	0.017*
339	0.201
402	0.545
450	1.341
512	2.822
558	3.894
CURVE 39	
435	0.486
294	0.000*
CURVE 40	
281	-0.044*
287	-0.014*
339	0.118*
392	0.305*
449	0.574
505	0.911
557	1.102

* Not shown in figure.

DATA TABLE 443. THERMAL LINEAR EXPANSION OF GLASS FIBER/EPOXY RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 41	
609	0.473
544	0.394
456	0.216
372	0.018
291	0.000*
CURVE 42	
270	-0.019
296	0.003*
339	0.046
395	0.098
439	0.126
511	0.162
575	0.150
626	0.156
CURVE 43	
557	0.098
456	0.067
340	0.014*
295	0.000*
CURVE 44	
264	-0.070*
294	-0.006*
294	0.006*
329	0.098*
393	0.231
503	1.524
CURVE 45*	
234	-0.067
223	-0.079
CURVE 46	
274	-0.012
295	0.000*
337	0.028
393	0.063*
463	0.097
507	0.118
563	0.128*
615	0.130*

T	$\Delta L/L_0$
CURVE 47	
595	0.141
439	0.060
349	0.023
CURVE 48	
258	-0.106
290	-0.010*
290	0.016*
335	0.071
395	0.251
460	0.667
513	1.185
572	1.582
CURVE 49*	
255	-0.051
222	-0.098
CURVE 50	
288	-0.024*
293	0.000*
341	0.110*
391	0.282
450	0.727
503	1.239
556	1.789
615	1.849
CURVE 51	
648	1.786
580	1.488
460	1.260
406	0.849
CURVE 52	
21	-0.675
53	-0.625
77	-0.577
84	-0.568
94	-0.548
100	-0.537
119	-0.487
129	-0.463

T	$\Delta L/L_0$
CURVE 52 (cont.)	
139	-0.446
148	-0.428
154	-0.415
164	-0.396
171	-0.376
178	-0.362
183	-0.351
189	-0.338
192	-0.327
197	-0.311
202	-0.294
207	-0.283
212	-0.267
216	-0.253
219	-0.244
224	-0.229
229	-0.214
236	-0.196
241	-0.183
246	-0.167
249	-0.151
254	-0.132*
258	-0.122
266	-0.102
275	-0.076
281	-0.049*
289	-0.028
292	-0.016*
298	0.003*
CURVE 53*	
77	-0.560
298	0.005
CURVE 54	
20	-0.133*
49	-0.127
79	-0.114
86	-0.112
92	-0.109
102	-0.105
108	-0.103
119	-0.098
137	-0.091
147	-0.086
154	-0.084

T	$\Delta L/L_0$
CURVE 54 (cont.)	
159	-0.081*
166	-0.078
171	-0.075
182	-0.069
188	-0.066
193	-0.063*
197	-0.060
204	-0.057
209	-0.056
215	-0.052
218	-0.048
224	-0.045*
229	-0.043
233	-0.039
239	-0.037
244	-0.033
248	-0.030
252	-0.028*
257	-0.024
260	-0.020
268	-0.016*
271	-0.014*
275	-0.010*
282	-0.007*
286	-0.004*
290	-0.002*
298	0.001*
CURVE 55	
5	-0.166
29	-0.161
79	-0.143*
301	0.002*
CURVE 56	
20	-0.160
77	-0.146
197	-0.078*
297	0.003*
CURVE 57*	
20	-0.135
77	-0.120
197	-0.063
297	0.003

T	$\Delta L/L_0$
CURVE 58*	
20	-0.153
77	-0.141
197	-0.075
297	0.003
CURVE 59*	
20	-0.163
77	-0.144
197	-0.075
297	0.003
CURVE 60	
20	-0.356
77	-0.319
197	-0.163
297	0.007*
CURVE 61	
20	-0.059*
77	-0.054*
197	-0.029
297	0.001*
CURVE 62*	
77	-0.112
120	-0.097
200	-0.057
297	0.002
CURVE 63*	
77	-0.121
120	-0.100
200	-0.056
297	0.002
CURVE 64*	
77	-0.057
120	-0.052
200	-0.032
297	0.001

T	$\Delta L/L_0$
CURVE 65*	
77	-0.111
120	-0.094
200	-0.056
297	0.002
CURVE 66	
17	-0.047
33	-0.048
61	-0.047
89	-0.045
116	-0.041
144	-0.036*
172	-0.031*
200	-0.025*
227	-0.018
255	-0.010*
283	-0.004*
294	0.000*
CURVE 67	
17	-0.409
33	-0.400
47	-0.389
61	-0.377
74	-0.365
89	-0.352
102	-0.334
116	-0.317
130	-0.299
144	-0.277
158	-0.254*
172	-0.232
186	-0.207
200	-0.182
213	-0.154
227	-0.127*
241	-0.100
255	-0.077*
269	-0.053
283	-0.023*
294	0.000*
CURVE 68	
17	-0.102
33	-0.101

* Not shown in figure.

DATA TABLE 443. THERMAL LINEAR EXPANSION OF GLASS FIBER/EPOXY RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 68 (cont.)	
61	-0.096
89	-0.089
16	-0.078
·	-0.070*
172	-0.058*
200	-0.045*
227	-0.034*
255	-0.019*
283	-0.005*
294	0.000*
CURVE 69	
17	-0.787
33	-0.778
47	-0.769
61	-0.755
74	-0.742
89	-0.728
102	-0.707
116	-0.684
130	-0.658
144	-0.623
158	-0.585
172	-0.547
186	-0.503
200	-0.454
213	-0.400
227	-0.344
241	-0.278
255	-0.213*
269	-0.130
283	-0.047*
294	0.000*
CURVE 70	
293	0.000*
298	0.006*
310	0.024
323	0.044
335	0.064*
348	0.088*
360	0.110
373	0.140*
385	0.170
398	0.204
411	0.232*
CURVE 71	
411	0.232*
398	0.212*
385	0.186*
373	0.166*
360	0.142
348	0.118
335	0.092
323	0.066*
310	0.038*
298	0.006*
293	0.000*
CURVE 72	
293	0.000*
298	0.001*
310	0.002*
323	0.004*
335	0.005
348	0.009*
360	0.012*
373	0.015*
385	0.019
398	0.023
399	0.025*
CURVE 73*	
399	0.025
398	0.025
385	0.023
373	0.020
360	0.016
348	0.012
335	0.010
323	0.006
310	0.003
298	0.001
293	0.000

* Not shown in figure.

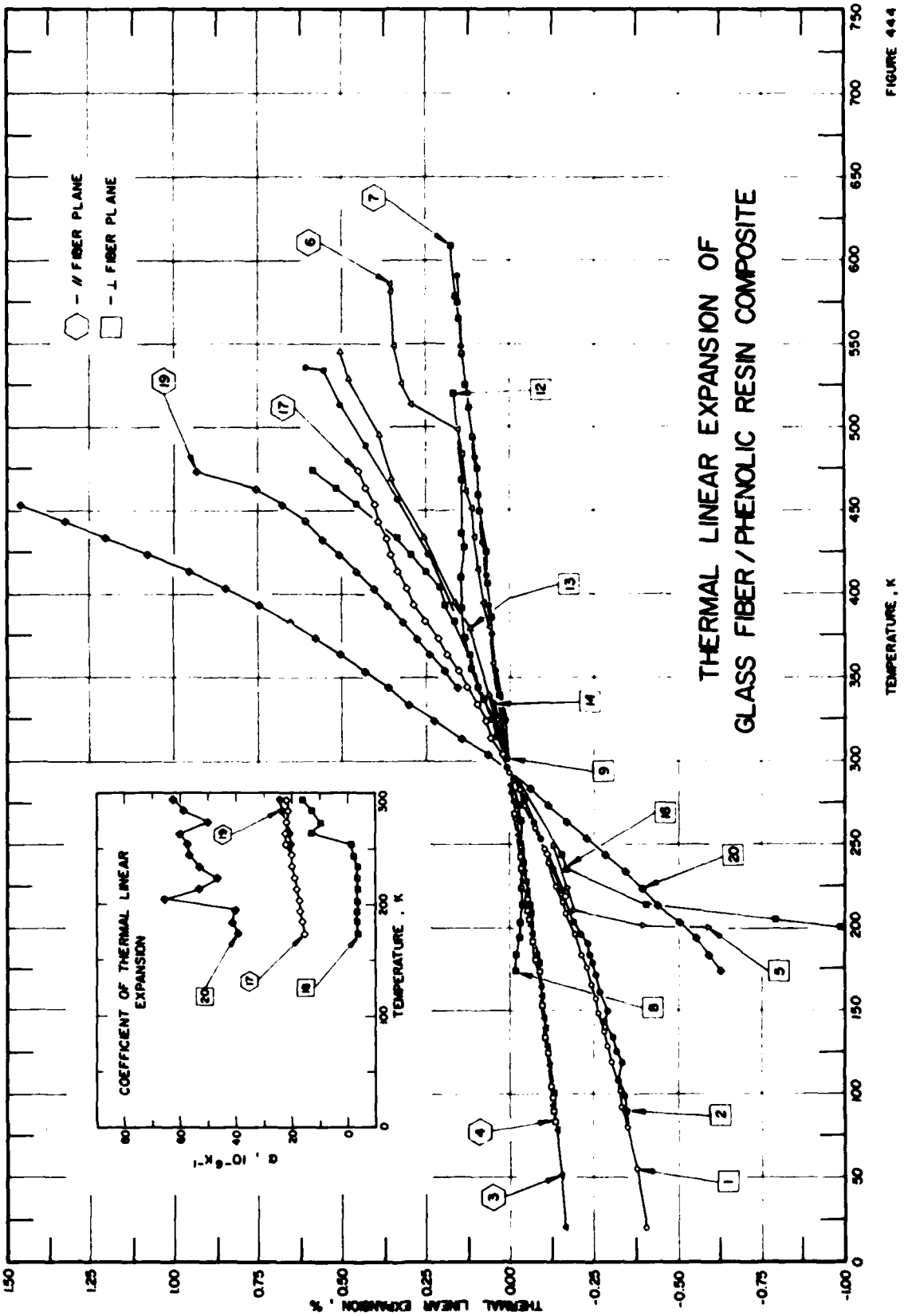

THERMAL LINEAR EXPANSION OF
GLASS FIBER / PHENOLIC RESIN COMPOSITE
- // FIBER PLANE
- ⊥ FIBER PLANE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶K⁻¹
TEMPERATURE , K

FIGURE 444

SPECIFICATION TABLE 444. THERMAL LINEAR EXPANSION OF GLASS FIBER/PHENOLIC RESIN COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	574	Haskins, J. F., Campbell, M. D., Hertz, J., and Percy, J. L.	1964	L	20-297	Glass fiber reinforced phenolic	Composition after measurement, 75.0 "E" glass cloth (MIL-C-9084, Type VIII (181) with MIL-F-9118 finish); 25.0 CTL-91-LD phenolic resin; sample 0.1 0.117 in. x 0.117 in. x 2.0 in. (maximum); expansion measured in the thickness direction by Leitz dilatometer to -320 F; data from -320 F to -420 F corrected; first run.
2	574	Haskins, J. F., et al.	1964	L	79-297	Glass fiber reinforced phenolic	The above specimen; immediately cycled while still in the dilatometer until no difference in the overall expansion observed; fourth cycle.
3	574	Haskins, J. F., et al.	1964	L	20-297	Glass fiber reinforced phenolic	Similar to the above specimen; sample taken from panel of 4.5" x 0.125" x 7"; expansion measured in the warp direction; first run; data obtained by Leitz dilatometer; subliquid nitrogen data below -320 F obtained by a vertical tube dilatometer and being corrected; first run.
4	574	Haskins, J. F., et al.	1964	L	79-296	Glass fiber reinforced phenolic	The above specimen; immediately cycled after first run, fourth cycle.
5*	574	Haskins, J. F., et al.	1964	L	19-297	Glass fiber reinforced phenolic	The above specimen; expansion measured in the weave direction; immediately cycled while still in the dilatometer until no difference in the overall expansion observed; second cycle.
6	1053	Melonas, J. V., Covington, P. C., and Pears, C. D.	1958		199-592	CTL 37-9X Laminate	Modified phenolic CTL 37-9X resin and 181 glass fabric; fabricated by Brunswick-Balke-Collender Co.; nominal thickness 1/8 in.; specimen 1 in. wide, 7 in. long; curving process: 411 K 1/2 hr at 175 psi, post cure: 394 K, 422 K, 450 K, and 477 K for 24 hr each; first run in longitudinal direction with respect to the fabric lay up; density (calculated) 103 lb. ft.$^{-3}$.
7	1053	Melonas, J. V., et al.	1958		293-609	CTL 37-9X Laminate	Second run of above specimen in longitudinal direction.
8*	1053	Melonas, J. V., et al.	1958		199-608	CTL 37-9X Laminate	Same curing process as that of above specimen; first run in transverse direction with respect to the fabric lay up.
9	1053	Melonas, J. V., et al.	1958		302-592	CTL 37-9X Laminate	Second run of above specimen in transverse direction.
10*	1053	Melonas, J. V., et al.	1958		199-592	CTL 37-9X Laminate	Same curing process as that of above specimen; first run in diagonal direction with respect to the fabric lay up.
11*	1053	Melonas, J. V., et al.	1958		293-610	CTL 37-9X Laminate	Second run of above specimen in diagonal direction.
12	1053	Melonas, J. V., et al.	1958		293-575	CTL 37-9X Laminate	Same except disk specimen with 1 in. diameter and 7 1/4 in. thickness; same curing process as that of above specimen; first run in thickness direction with respect to the fabric lay up.
13	1053	Melonas, J. V., et al.	1958		293-545	CTL 37-9X Laminate	Second run of above specimen in thickness direction.
14	1053	Melonas, J. V., et al.	1958		293-536	CTL 37-9X Laminate	Third run of above specimen in thickness direction.

* Not shown in figure.

SPECIFICATION TABLE 444. THERMAL LINEAR EXPANSION OF GLASS FIBER/PHENOLIC RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
15	1053	Melonas, J.V., Covington, P.C., and Pears, C.D.	1958		293-200	CTL 37-2X Laminate	Same curing process as that of above specimen; first run in thickness direction with respect to the fabric lay up; cooling cycle.
16	1053	Melonas, J.V., et al.	1958		293-200	CTL 37-2X Laminate	Second run of above specimen in thickness direction; cooling cycle.
17	171	Asay, J.R.	1968		173-473		Avco phenolic fiberglass; phenol-farmaldehyde thermo-setting resin laminated with glass fibers; density 1.71 g cm^{-3}; expansion measured parallel to fibers.
18	171	Asay, J.R.	1968		173-473		The above specimen, expansion perpendicular to fibers.
19	171	Asay, J.R.	1968		173-473		G.E. Phenolic Fiberglass; expansion parallel to fibers.
20	171	Asay, J.R.	1968		173-473		The above specimen, expansion perpendicular to fibers.

DATA TABLE 444. THERMAL LINEAR EXPANSION OF GLASS FIBER/PHENOLIC RESIN COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
20	-0.408
55	-0.376
79	-0.355
93	-0.337
102	-0.328
109	-0.317*
119	-0.307
129	-0.295
138	-0.280
148	-0.267
157	-0.257
165	-0.244
176	-0.230
183	-0.216
188	-0.203*
196	-0.196
200	-0.184*
208	-0.168
215	-0.160
221	-0.148*
225	-0.140
232	-0.128*
238	-0.117
247	-0.101
253	-0.088*
260	-0.075
264	-0.064*
273	-0.048
275	-0.045*
283	-0.027
289	-0.012*
293	0.000
297	0.007*
CURVE 2	
79	-0.357*
90	-0.346
99	-0.341
108	-0.325
118	-0.333
125	-0.322
134	-0.311
144	-0.280
150	-0.290
161	-0.273
CURVE 2 (cont.)	
172	-0.260
178	-0.249
184	-0.239
191	-0.229
197	-0.211
204	-0.188
210	-0.177*
216	-0.170*
223	-0.154
228	-0.146*
236	-0.130
241	-0.119*
253	-0.095
257	-0.083*
264	-0.074
267	-0.060*
276	-0.040
283	-0.022*
289	-0.010
295	0.006*
297	0.009
CURVE 3	
20	-0.166
51	-0.154
78	-0.144
84	-0.141*
93	-0.137
101	-0.132
107	-0.128*
118	-0.123
129	-0.116
139	-0.111
145	-0.107
151	-0.103*
158	-0.100
164	-0.094
169	-0.091*
178	-0.087
184	-0.083
187	-0.079*
196	-0.074
202	-0.070
208	-0.066
214	-0.061
CURVE 3 (cont.)	
221	-0.056
228	-0.051
233	-0.047
238	-0.043
246	-0.037
250	-0.033
256	-0.028
263	-0.023*
270	-0.020*
276	-0.014
282	-0.009
287	-0.005
293	0.000*
297	0.0009*
CURVE 4	
79	-0.140*
83	-0.138
90	-0.134
98	-0.129
105	-0.125
116	-0.121*
125	-0.116
134	-0.110
143	-0.105*
153	-0.099
158	-0.096*
165	-0.090*
173	-0.087
179	-0.083
183	-0.079*
192	-0.073
196	-0.069*
205	-0.065
210	-0.061
217	-0.055
223	-0.051
233	-0.045*
237	-0.042
243	-0.037
249	-0.033*
256	-0.028*
261	-0.024
268	-0.019
274	-0.014*
CURVE 4 (cont.)	
281	-0.008*
287	-0.003*
293	-0.000*
296	0.003*
CURVE 5*	
19	-0.152
52	-0.143
79	-0.137
85	-0.136
87	-0.133
95	-0.129
104	-0.125
115	-0.120
121	-0.116
131	-0.111
141	-0.105
150	-0.098
160	-0.094
169	-0.088
180	-0.082
183	-0.078
191	-0.073
196	-0.070
203	-0.064
209	-0.061
216	-0.056
223	-0.051
230	-0.047
234	-0.043
239	-0.038
244	-0.035
253	-0.030
258	-0.027
263	-0.024
269	-0.018
276	-0.012
282	-0.007
288	-0.003
294	-0.001
297	0.001
CURVE 6	
199	-0.069*
CURVE 6 (cont.)	
210	-0.063*
222	-0.056*
233	-0.048*
244	-0.040*
255	-0.031*
266	-0.024
283	-0.004*
324	0.020
358	0.047
380	0.060
395	0.074
415	0.087
434	0.104
451	0.116
462	0.126
484	0.143
498	0.154
513	0.296
527	0.322
549	0.339
577	0.352
592	0.359
CURVE 7	
293	0.000*
338	0.029
360	0.043*
386	0.057
406	0.066
425	0.072
448	0.083
459	0.096
475	0.099
493	0.111
512	0.124
525	0.134
544	0.143
565	0.154
578	0.160
609	0.176
CURVE 8*	
199	-0.077
210	-0.066
CURVE 8 (cont.)*	
222	-0.059
233	-0.048
244	-0.043
255	-0.036
266	-0.022
283	-0.006
333	0.021
354	0.033
383	0.053
403	0.066
423	0.077
440	0.090
428	0.097
473	0.105
492	0.118
507	0.130
524	0.137
542	0.147
561	0.152
577	0.156
608	0.235
CURVE 9	
302	0.005
323	0.018
354	0.044*
376	0.050
393	0.064
412	0.070
431	0.080
449	0.087*
462	0.094*
482	0.105
496	0.114*
513	0.124*
526	0.132*
548	0.144
577	0.152*
592	0.155
CURVE 10*	
199	-0.083
210	-0.074
222	-0.066

* Not shown in figure.

DATA TABLE 444. THERMAL LINEAR EXPANSION OF GLASS FIBER/PHENOLIC RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 10 (cont.)*	
233	-0.057
244	-0.047
255	-0.037
266	-0.025
283	-0.010
324	0.011
356	0.036
378	0.049
395	0.062
414	0.072
433	0.083
451	0.090
462	0.096
482	0.105
497	0.111
513	0.119
528	0.123
549	0.127
577	0.127
592	0.127
CURVE 11*	
293	0.000
335	0.023
357	0.037
385	0.056
405	0.068
425	0.080
448	0.093
459	0.097
474	0.106
494	0.117
501	0.127
524	0.135
545	0.144
565	0.146
579	0.146
610	0.151
CURVE 12	
293	0.000*
302	0.015*
314	0.033
337	0.076
355	0.115
373	0.140
392	0.146
410	0.146
428	0.132
437	0.138
468	0.141
485	0.151*
498	0.158*
520	0.170
575	0.155
CURVE 13	
293	0.000*
302	0.014*
323	0.028*
338	0.065
378	0.123
396	0.163
433	0.254
469	0.354
495	0.391
529	0.477
545	0.507
CURVE 14	
293	0.000*
317	0.026*
334	0.054
372	0.130*
395	0.172*
424	0.244
457	0.330
489	0.429
514	0.502
534	0.553
536	0.613
CURVE 15	
293	0.000
249	-0.128
224	-0.172
210	-0.191
202	-0.399
200	-0.591
CURVE 16	
293	0.000*
243	-0.154
235	-0.173
214	-0.402
205	-0.798
200	-0.988
CURVE 17‡	
173	-0.237*
183	-0.221*
193	-0.205*
203	-0.187*
213	-0.169
223	-0.150*
233	-0.130*
243	-0.110
253	-0.089*
263	-0.066*
273	-0.044*
283	-0.022*
293	0.000*
303	0.022
313	0.046*
323	0.071
333	0.098
343	0.127
353	0.157
363	0.187
373	0.218
383	0.251
393	0.283
403	0.310
413	0.332
423	0.353
433	0.373
443	0.390
453	0.407
463	0.428
473	0.452
CURVE 18‡	
173	-0.020
183	-0.023
193	-0.027
203	-0.030
213	-0.034
223	-0.037
233	-0.040*
243	-0.043*
253	-0.045*
263	-0.038
273	-0.027
283	-0.015*
293	0.000*
303	0.015*
313	0.033*
323	0.057
333	0.080*
343	0.099
353	0.112*
363	0.124
373	0.142*
383	0.169
393	0.189
403	0.210
413	0.249
423	0.290
433	0.329
443	0.385*
453	0.454
463	0.516
473	0.586
CURVE 19‡	
173	-0.236*
183	-0.220*
193	-0.203*
203	-0.186*
213	-0.168*
223	-0.150*
233	-0.130*
243	-0.110*
253	-0.089*
263	-0.068*
273	-0.046*
283	-0.024*
293	0.000*
303	0.026*
313	0.054*
323	0.085*
333	0.117*
343	0.153
353	0.192
363	0.232
373	0.275
383	0.319
393	0.364
403	0.409
413	0.456
423	0.506
433	0.559
443	0.615
453	0.676
463	0.755
473	0.934
CURVE 20‡	
173	-0.636
183	-0.596
193	-0.555
203	-0.501
213	-0.441
223	-0.391
233	-0.341
243	-0.286
253	-0.229
263	-0.170
273	-0.115
283	-0.061
293	0.000*
303	0.068
313	0.145
323	0.225
333	0.300
343	0.365
353	0.431
363	0.504
373	0.577
383	0.658
393	0.747
403	0.845
413	0.959
423	1.079
433	1.201
443	1.324
453	1.454
463	1.590*
473	1.731*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 444. COEFFICIENT OF THERMAL LINEAR EXPANSION OF GLASS FIBER/PHENOLIC RESIN COMPOSITE

(Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1})

T	α
CURVE 17‡	
173	15.80
183	16.10
193	17.20
203	17.50
213	18.80
223	19.20
233	20.20
243	20.20
253	22.50
263	22.60
273	22.20
283	21.80
293	22.20
303	22.20*
313	24.90*
323	25.50*
333	28.60*
343	28.90*
353	30.90*
363	30.30*
373	31.60*
383	34.30*
393	30.20*
403	22.80*
413	21.80*
423	20.80*
433	18.20*
443	15.50*
453	18.80*
463	22.50*
473	25.50*
CURVE 18‡	
173	-3.4
183	-3.4
193	-3.4
203	-3.4
213	-3.4
223	-3.4
233	-3.4
243	-2.0
253	-1.0
263	13.4
273	10.0
283	13.4
293	16.7
303	13.4*
313	23.4*
323	23.4*
333	23.4*
343	13.4*
353	13.3*
363	10.0*
373	26.7*
383	26.7*
393	13.4*
403	30.0*
413	46.5*
423	36.7*
433	40.1*
443	73.4*
453	63.4*
463	60.1*
473	80.0*
CURVE 19‡	
173	15.30*
183	16.00*
193	17.30*
203	17.30*
213	18.00*
223	19.00*
233	20.00*
243	20.30*
253	21.30
263	21.60
273	21.60*
283	23.60
293	24.00
303	27.30
313	29.90*
323	31.00*
333	34.60*
343	37.40*
353	39.50*
363	41.50*
373	43.40*
383	44.50*
393	45.00*
403	45.60*
413	48.90*
423	51.20*
433	53.90*
443	58.20*
453	63.90*
463	93.80*
473	265.80*
CURVE 20‡	
173	39.50
183	41.70
193	40.10
203	66.70
213	53.40
223	46.70
233	53.10
243	56.70
253	57.70
263	60.10
273	50.10
283	59.00
293	62.50
303	73.40*
313	80.10*
323	80.10*
333	70.10*
343	60.10*
353	72.30*
363	72.50*
373	73.50*
383	90.20*
393	86.80*
403	110.10*
413	116.80*
423	123.50*
433	120.10*
443	126.80*
453	133.50*
463	136.80*
473	146.80*

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

SPECIFICATION TABLE 445. THERMAL LINEAR EXPANSION OF GLASS FIBER/PHENYL SILANE RESIN COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	574	Haskins, J. F., Campbell, M. D., Hertz, J., and Percy, J. L.	1964	L	22-298	G	69.0 Owens corning X-994 woven glass fabric containing an A-1100 finish; 31.0 Monsanto SC-1013 phenyl silane resin; reinforcements consist of parallel layers of cloth; a series of 0.5 in. wide pieces cut in the thickness direction stacked end to end and bonded to form specimen of 0.117 in. x 0.117 in. x 2.0 in.; corrected sub-liquid nitrogen data obtained by vertical tube dilatometer; expansion measured in the thickness direction.
2*	574	Haskins, J. F., et al.	1964	L	80, 293	G	The above specimen; immediately cycled while still in the dilatometer; fourth cycle; expansion in the thickness direction.
3*	574	Haskins, J. F., et al.	1964	L	22-298	G	The above specimen; expansion measured normal to thickness in the warp direction; corrected sub-liquid nitrogen recorded; first run.
4*	574	Haskins, J. F., et al.	1964	L	81, 293	G	The above specimen; expansion measured normal to thickness in the warp direction; fourth cycle.
5*	574	Haskins, J. F., et al.	1964	L	22-298	G	The above specimen; expansion measured normal to thickness in the weave direction; corrected sub-liquid nitrogen recorded; first run.

* No figure given.

DATA TABLE 445. THERMAL LINEAR EXPANSION OF GLASS FIBER/PHENYL SILANE RESIN COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
22	-0.578
61	-0.537
79	-0.513
87	-0.501
97	-0.490
105	-0.470
113	-0.459
124	-0.437
132	-0.425
141	-0.407
148	-0.397
158	-0.378
168	-0.358
174	-0.349
180	-0.336
187	-0.317
192	-0.303
199	-0.288
205	-0.273
213	-0.256
219	-0.235
224	-0.219
230	-0.202
238	-0.185
243	-0.172
249	-0.149
255	-0.131
262	-0.110
269	-0.087
273	-0.070
279	-0.049
288	-0.025
292	0.000
298	0.003
CURVE 2*	
80	0.492
293	0.000
CURVE 3*	
22	-0.127
52	-0.117
99	-0.108
90	-0.104
98	-0.101
108	-0.098
117	-0.094
124	-0.091
134	-0.086
143	-0.082
150	-0.078
159	-0.073
169	-0.069
174	-0.066
181	-0.062
188	-0.059
195	-0.057
199	-0.053
208	-0.049
213	-0.046
220	-0.042
225	-0.040
229	-0.037
237	-0.033
242	-0.028
248	-0.024
255	-0.021
262	-0.017
268	-0.012
273	-0.007
279	-0.006
287	-0.002
293	0.000
298	0.003
CURVE 4*	
81	-0.104
293	0.000
CURVE 5*	
22	-0.134
53	-0.122
81	-0.112
88	-0.110
98	-0.107
107	-0.104
113	-0.100
122	-0.096
133	-0.091
138	-0.088
149	-0.084
157	-0.080
166	-0.076
175	-0.071
178	-0.069
184	-0.066
192	-0.062
199	-0.057
204	-0.054
211	-0.050
216	-0.048
223	-0.043
227	-0.041
233	-0.037
239	-0.035
247	-0.028
252	-0.023
259	-0.018
264	-0.016
267	-0.014
274	-0.009
281	-0.005
288	-0.002
293	0.000
298	0.002

* No figure given.

SPECIFICATION TABLE 446. THERMAL LINEAR EXPANSION OF GLASS FIBER/SILICONE RESIN COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	574	Haskins, J. F., Campbell, M. D., Hertz, J., and Percy, J. L.	1964	L	20-297	F	69.0 heat cleaned "E" glass fiber roving; 31.0 Dow Corning DC-2106 silicone resin; a series of 0.5 in. wide pieces cut in the thickness direction from panel of 10 in. x 0.5 in. x 14 in.; stacked end to end and bonded to form specimen of 0.117 in. x 0.117 in. x 2.0 in.; Leitz dilatometer used to 80 C; sub-liquid nitrogen data obtained by vertical tube dilatometer and corrected; expansion measured in the thickness direction; first run.
2*	574	Haskins, J. F., et al.	1964	L	79, 297		The above specimen; immediately cycled while still in the dilatometer until no difference in the overall expansion observed; expansion measured in the thickness direction; third cycle.
3*	574	Haskins, J. F., et al.	1964	L	20-298		The above specimen; corrected sub-liquid nitrogen data recorded; expansion measured normal to thickness direction; first run.
4*	574	Haskins, J. F., et al.	1964	L	81-298		The above specimen; expansion measured normal to thickness direction; fourth cycle.

DATA TABLE 446. THERMAL LINEAR EXPANSION OF GLASS FIBER/SILICONE RESIN COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$	T	$\Delta L/L_0$
CURVE 1*		CURVE 1 (cont.)*		CURVE 1 (cont.)*		CURVE 3 (cont.)*		CURVE 3 (cont.)*	
20	-0.612	191	-0.280	290	-0.009	121	-0.094	244	-0.027
55	-0.555	197	-0.272	293	-0.0001	130	-0.090	249	-0.025
79	-0.508	203	-0.251	297	0.0022	139	-0.086	254	-0.021
87	-0.494	208	-0.245			148	-0.082	259	-0.019
95	-0.478	214	-0.228	CURVE 2*		158	-0.078	267	-0.015
103	-0.462	218	-0.217			106	-0.074	272	-0.013
112	-0.451	225	-0.202	79	-0.480	172	-0.071	279	-0.008
119	-0.436	229	-0.193	297	0.002	179	-0.067	284	-0.005
128	-0.423	234	-0.170			184	-0.064	288	-0.002
135	-0.406	240	-0.160	CURVE 3*		190	-0.060	293	0.000
142	-0.393	247	-0.142			196	-0.055	298	0.0032
153	-0.366	252	-0.126	20	-0.129	202	-0.053		
159	-0.356	258	-0.106	51	-0.121	208	-0.050	CURVE 4*	
166	-0.343	263	-0.090	81	-0.110	212	-0.046		
169	-0.337	269	-0.070	87	-0.107	219	-0.041	81	-0.109
174	-0.323	272	-0.061	97	-0.103	224	-0.040	298	0.003
180	-0.310	277	-0.045	104	-0.100	232	-0.035		
185	-0.294	283	-0.025	113	-0.097	236	-0.032		

* No figure given.

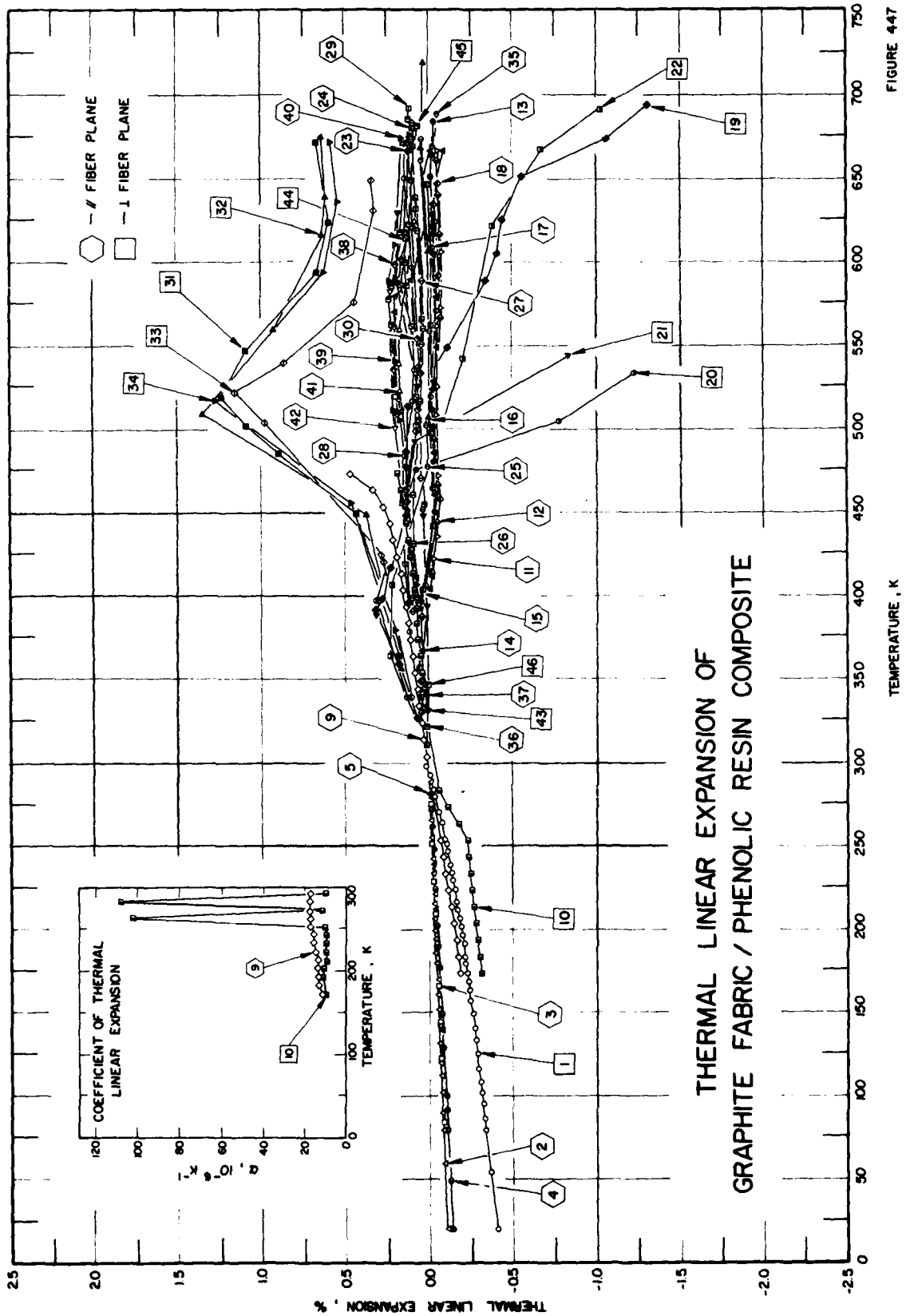

THERMAL LINEAR EXPANSION OF
GRAPHITE FABRIC / PHENOLIC RESIN COMPOSITE
// FIBER PLANE
⊥ FIBER PLANE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K

FIGURE 447

SPECIFICATION TABLE 447. THERMAL LINEAR EXPANSION OF GRAPHITE FABRIC/PHENOLIC RESIN COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	574	Haskins, J. F., Campbell, M. D., Herts, J., and Percy, J. L.	1964	L	20-298		Fabric reinforced laminate; 70.0 National Carbon Co. WCB graphite fabric; 30.0 Monsanto SC-1008 phenolic resin; a series of 0.5 in. wide pieces, cut in the thickness direction from 10 in. x 0.5 in. x 14 in. panel, stacked end to end, bonded to form 0.117 in. x 0.117 in. x 2.0 in. specimen; sub-liquid nitrogen data corrected, obtained by vertical tube dilatometer; expansion measured in the thickness direction; first run.
2	574	Haskins, J. F., et al.	1964	L	20-293		Similar to the above specimen; sample taken from panel 4.5 in. x 0.125 in. x 7 in.; expansion measured normal to thickness in the warp direction; sub-liquid nitrogen data corrected; first run.
3	574	Haskins, J. F., et al.	1964	L	78-298		The above specimen; immediately cycled while still in the dilatometer until no difference in the overall expansion observed; fourth cycle.
4	574	Haskins, J. F., et al.	1964	L	20-297		The above specimen; expansion measured normal to thickness in the weave direction; sub-liquid nitrogen data corrected; first run.
5	574	Haskins, J. F., et al.	1964	L	79-297		The above specimen; immediately cycled while still in the dilatometer; fourth cycle; expansion measured normal to thickness in the weave direction.
6*	371	Dull, R. B.	1964		293-1273	PT-0110 Graphite-cloth Laminate	Sample consists of layers of graphite-cloth bonded together by a suitable carbonaceous binder and baked to (800 C) 1073 K; National Carbon Co.; specimen dimensions 0.5 by 0.5 by 5 in.; specimen taken from 0.5 in. by 6 in. block; specific resistance parallel to grain 116 x 10^{-4} ohm-cm at room temperature; average data over several runs; bulk density 1.14 g cm^{-3} at room temperature; measured parallel to grain.
7*	371	Dull, R. B.	1964		293-2873	PT-0111 Graphite-cloth Laminate	Same as above specimen except graphite cloth bonded together by a suitable carbonaceous binder and graphitized; specific resistance parallel to grain 32.4 x 10^{-4} ohm-cm at room temperature; bulk density 1.11 g cm^{-3} at room temperature.
8*	371	Dull, R. B.	1964		293-2873	PT-0156 Graphite-cloth Laminate	Sample consists of layers of graphite cloth bonded together by suitable carbonaceous binder and graphitized; National Carbon Co.; specimen taken from 0.5 by 6 by 6 in. block; specimen dimensions 0.5 by 0.5 by 5 in.; average data over several runs; specific resistance parallel to grain 30.6 x 10^{-4} ohm-cm at room temperature; bulk density 1.29 g cm^{-3} at room temperature; measured parallel to grain.
9	171	Asay, J. R.	1968		173-473		General Electric prepregnated carbon phenolic; 34% phenolic resin and carbon cloth filaments; density 1.48 g cm^{-3}; decomposes at 748 K; expansion measured parallel to cloth.
10	171	Asay, J. R.	1968		173-473		The above specimen; expansion measured perpendicular to cloth.
11	1055	Pears, C. D., Engelke, W. T., and Thornburgh, J. D.	1965	L	296-667	Specimen 1	58% graphite fabric, plain woven, 17 plies/0.635 cm; 42% USP 39 carbon-filled phenyl aldehyde resin; cured to 200 psig for 12 hr and 360 F for 4 hr; specimen fabricated by Roler Corp.; expansion measured in warp direction; initial length 3.0082 in; reported error ±5%.
12	1055	Pears, C. D., et al.	1965	L	296-661	FM-5064 Specimen 2	Similar to the above specimen; initial length 3.0074 in.
13	1055	Pears, C. D., et al.	1965	L	286-684	FM-5064 Specimen 3	Similar to the above specimen; initial length 3.0066 in.

* Not shown in figure.

SPECIFICATION TABLE 447. THERMAL LINEAR EXPANSION OF GRAPHITE FABRIC/PHENOLIC RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
14	1055	Pears, C.D., Engelke, W.T., and Thornburgh, J.D.	1965	L	286-683	FM-5064 Specimen 4	Similar to the above specimen; initial length 3.0089 in.
15	1055	Pears, C.D., et al.	1965	L	293-646	FM-5064 Specimen 1	Similar to the above specimen; expansion measured in fill direction; initial length 3.0072 in.
16	1055	Pears, C.D., et al.	1965	L	293-719	FM-5064 Specimen 2	Similar to the above specimen; initial length 3.0067 in.
17	1055	Pears, C.D., et al.	1965	L	293-663	FM-5064 Specimen 3	Similar to the above specimen; initial length 3.0075 in.
18	1055	Pears, C.D., et al.	1965	L	293-683	FM-5064 Specimen 4	Similar to the above specimen; initial length 3.0085 in.
19	1055	Pears, C.D., et al.	1965	L	293-694	FM-5064 Specimen 1	Similar to the above specimen; expansion measured across lamina; initial length 2.8972 in.
20	1055	Pears, C.D., et al.	1965	L	293-533	FM-5064 Specimen 2	Similar to the above specimen; initial length 2.8573 in.
21	1055	Pears, C.D., et al.	1965	L	293-543	FM-5064 Specimen 3	Similar to the above specimen; initial length 2.8687 in.
22	1055	Pears, C.D., et al.	1965	L	293-691	FM-5064 Specimen 4	Similar to the above specimen; initial length 2.8805 in.
23	1055	Pears, C.D., et al.	1965	L	293-666	ACX-G79 Specimen 1	71% WCA graphite fabric, square weave from National Carbon Co.; 25 plies/0.64 cm; warp cross plied 90°; 29% Pyropreg ACX-G79 carbonaceous and ceramic filled phenolic resin; cured up to 10 min under 1000 psig, then 3 hr at 300 to 315 F and 400 psig; specimens fabricated by Thompson Ramo Wooldridge, Inc.; expansion measured with lamina in a direction; initial length 3.0016 in.; reported error ±5%.
24	1055	Pears, C.D., et al.	1965	L	293-680	ACX-G79 Specimen 2	Similar to the above specimen; initial length 3.0015 in.
25	1055	Pears, C.D., et al.	1965	L	293-673	ACX-G79 Specimen 3	Similar to the above specimen; initial length 2.9974 in.
26	1055	Pears, C.D., et al.	1965	L	293-673	ACX-G79 Specimen 4	Similar to the above specimen; initial length 3.0005 in.
27	1055	Pears, C.D., et al.	1965	L	293-683	ACX-G79 Specimen 1	Similar to the above specimen; expansion measured with lamina in b direction; initial length 3.0026 in.
28	1055	Pears, C.D., et al.	1965	L	293-671	ACX-G79 Specimen 2	Similar to the above specimen; initial length 2.9991 in.
29	1055	Pears, C.D., et al.	1965	L	293-692	ACX-G79 Specimen 3	Similar to the above specimen; initial length 3.0003 in.
30	1055	Pears, C.D., et al.	1965	L	293-673	ACX-G79 Specimen 4	Similar to the above specimen; initial length 2.9998 in.
31	1055	Pears, C.D., et al.	1965	L	296-672	ACX-G79 Specimen 1	Similar to the above specimen; expansion measured across lamina; initial length 3.0005 in.

SPECIFICATION TABLE 447. THERMAL LINEAR EXPANSION OF GRAPHITE FABRIC/PHENOLIC RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
32	1055	Pears, C.D., Engelke, W.T., and Thornburgh, J.D.	1965	L	296-675	ACX-G79 Specimen 2	Similar to the above specimen; initial length 2.9968 in.
33	1055	Pears, C.D., et al.	1965	L	296-648	ACX-G79 Specimen 3	Similar to the above specimen; initial length 2.9984 in.
34	1055	Pears, C.D., et al.	1965	L	296-672	ACX-G79 Specimen 4	Similar to the above specimen; initial length 2.9968 in.
35	1055	Pears, C.D., et al.	1965	L	293-688	MX4926 Specimen 1	59% HITCO-CCA-1 graphite fabric, satin weave, 25 plies/0.64 cm; warp cross-plied 90°; 41% MIL-R-9299, type II phenolic resin filled with 5 to 10% carbon; program cured to 3 hr at 423 K and 400 psi; specimen fabricated by Thompson Ramo Wooldridge Inc.; expansion measured with lamina in a-direction; initial length 3.0004 in.; reported error ±5%.
36	1055	Pears, C.D., et al.	1965	L	293-685	MX4926 Specimen 2	Similar to the above specimen; initial length 3.0007 in.
37	1055	Pears, C.D., et al.	1965	L	293-666	MX4926 Specimen 3	Similar to the above specimen; initial length 3.0003 in.
38	1055	Pears, C.D., et al.	1965	L	293-673	MX4926 Specimen 4	Similar to the above specimen; initial length 3.0000 in.
39	1055	Pears, C.D., et al.	1965	L	293-676	MX4926 Specimen 1	Similar to the above specimen; expansion measured with lamina in b-direction; initial length 3.0007 in.
40	1055	Pears, C.D., et al.	1965	L	293-674	MX4926 Specimen 2	Similar to the above specimen; initial length 3.0008 in.
41	1055	Pears, C.D., et al.	1965	L	293-673	MX4926 Specimen 3	Similar to the above specimen; initial length 3.0009 in.
42	1055	Pears, C.D., et al.	1965	L	293-666	MX4926 Specimen 4	Similar to the above specimen; initial length 3.0024 in.
43	1055	Pears, C.D., et al.	1965	L	293-676	MX4926 Specimen 1	Similar to the above specimen; expansion measured across lamina; initial length 2.990 in.
44	1055	Pears, C.D., et al.	1965	L	293-671	MX4926 Specimen 2	Similar to the above specimen; initial length 2.9992 in.
45	1055	Pears, C.D., et al.	1965	L	293-681	MX4926 Specimen 3	Similar to the above specimen; initial length 2.9952 in.
46	1055	Pears, C.D., et al.	1965	L	[illegible]-678	MX4926 Specimen 4	Similar to the above specimen; initial length 2.9983 in.

DATA TABLE 447. THERMAL LINEAR EXPANSION OF GRAPHITE FABRIC/PHENOLIC RESIN COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
20	-0.402
54	-0.365
79	-0.339
86	-0.330
95	-0.322
102	-0.316
108	-0.306
116	-0.298
125	-0.289
133	-0.277
140	-0.272
149	-0.259
157	-0.249
163	-0.240
168	-0.236
173	-0.226
179	-0.218
183	-0.213
191	-0.203
196	-0.193
201	-0.186
206	-0.176
211	-0.168
216	-0.161
224	-0.152
229	-0.142
234	-0.132
238	-0.123
246	-0.109
251	-0.103
254	-0.095
258	-0.091*
264	-0.079
270	-0.061
274	-0.048*
279	-0.037
284	-0.024
292	0.000
294	0.008*
298	0.022
CURVE 2	
20	-0.1108
59	-0.0990
79	-0.0890
89	-0.0842
102	-0.0795
112	-0.0748
119	-0.0722
131	-0.0667
141	-0.0635
151	-0.0595
160	-0.0567
169	-0.0521
179	-0.0477
185	-0.0447
194	-0.0420
198	-0.0400
206	-0.0365
215	-0.0342
221	-0.0320
225	-0.0298*
233	-0.0267
242	-0.0245
249	-0.0210*
255	-0.0189
261	-0.0163*
265	-0.0140
269	-0.0118*
278	-0.0088
283	-0.0055*
288	-0.0039
291	-0.0024*
293	0.0000*
CURVE 3	
78	-0.091*
84	-0.089
91	-0.086*
102	-0.082*
113	-0.078*
122	-0.073
132	-0.069*
144	-0.063
153	-0.059*
165	-0.055
173	-0.051*
181	-0.048*
186	-0.046*
195	-0.042*
200	-0.039*
208	-0.035
213	-0.032*
222	-0.029*
228	-0.027
235	-0.023*
242	-0.021*
251	-0.017
257	-0.015*
265	-0.011*
275	-0.008
282	-0.005*
289	-0.002*
293	0.000*
298	0.002*
CURVE 4	
20	-0.134
48	-0.125
79	-0.109
83	-0.107*
92	-0.104
100	-0.101
108	-0.096*
118	-0.091*
129	-0.086
139	-0.082*
149	-0.076
158	-0.072*
167	-0.066*
177	-0.062
183	-0.028*
189	-0.055
195	-0.052*
202	-0.048
208	-0.046*
215	-0.042*
223	-0.037
228	-0.034*
236	-0.029*
242	-0.027*
248	-0.024
253	-0.021*
262	-0.017
268	-0.014*
272	-0.011
279	-0.008*
286	-0.003*
288	-0.001*
293	0.000*
297	0.004*
CURVE 5	
79	-0.111*
100	-0.099*
112	-0.095*
120	-0.089*
130	-0.084*
139	-0.080
150	-0.074*
160	-0.069*
168	-0.064*
179	-0.059*
184	-0.056*
193	-0.052*
199	-0.049*
207	-0.044*
212	-0.041
219	-0.036*
226	-0.033*
234	-0.029*
239	-0.027
246	-0.025*
254	-0.020*
264	-0.015*
273	-0.010*
281	-0.006
287	-0.003*
294	0.0005*
297	0.005*
CURVE 6*	
293	0.000
473	0.023
673	0.047
873	0.078
1073	0.128
1272	0.197
CURVE 7*	
293	0.000
773	0.076
1273	0.098
1773	0.358
2273	0.551
2673	0.722
2873	0.823
CURVE 8*	
293	0.000
773	0.078
1273	0.215
1773	0.377
2273	0.597
2673	0.778
2873	0.850
CURVE 9	
173	-0.180
183	-0.168
193	-0.155
203	-0.142
213	-0.128
223	-0.114
233	-0.099
243	-0.084
253	-0.067
263	-0.050*
273	-0.033*
283	-0.016*
293	0.000
303	0.015
313	0.029
323	0.043
333	0.056
343	0.068
353	0.079
363	0.091
373	0.104
383	0.118
393	0.134
403	0.151
413	0.169
423	0.189
433	0.211
443	0.237
453	0.272
463	0.330
473	0.468
CURVE 10	
173	-0.313
183	-0.302
193	-0.290
203	-0.279
213	-0.269
223	-0.260
233	-0.250
243	-0.241
253	-0.231
263	-0.175
273	-0.118
283	-0.059
293	0.000*
303	0.010*
313	0.018*
323	0.025*
333	0.031*
343	0.037
353	0.042
363	0.049
373	0.057
383	0.064
393	0.071
403	0.080
413	0.091
423	0.105
433	0.120
443	0.134
453	0.148
463	0.165
473	0.187
CURVE 11	
296	0.001*
343	0.027*
422	-0.045
435	-0.058
472	-0.065
508	-0.051
561	-0.061
572	-0.081

* Not shown in figure.

DATA TABLE 447. THERMAL LINEAR EXPANSION OF GRAPHITE FABRIC/PHENOLIC RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 11 (cont.)	
606	-0.088
667	-0.067
CURVE 12	
296	0.001*
342	0.041*
387	0.047
444	-0.055
466	-0.059
493	-0.041
566	-0.075
616	-0.075
640	-0.061
661	-0.055
CURVE 13	
286	0.000*
396	0.043
450	-0.042
480	-0.042
501	-0.033
511	-0.023
621	-0.035
651	-0.020
664	-0.030
684	-0.046
CURVE 14	
286	0.000*
333	0.036*
366	0.043
389	0.030*
404	-0.007
411	-0.026
460	-0.046
485	-0.032
523	-0.025
528	-0.040
548	-0.056
579	-0.052
604	-0.041
617	-0.040
628	-0.026
650	-0.016*
666	-0.016
683	-0.023*

T	$\Delta L/L_0$
CURVE 15	
293	0.000*
356	0.050
363	0.050*
373	0.053*
403	0.030
441	-0.029
497	-0.019
561	-0.029
614	-0.016
646	0.000
CURVE 16	
293	0.000*
342	0.050*
397	0.040*
485	-0.012*
507	-0.006
563	-0.022*
606	-0.006
668	0.033
719	0.020
CURVE 17	
293	0.000*
357	0.040*
406	0.020
464	-0.029
519	-0.012
570	-0.056
608	-0.029
663	-0.003*
CURVE 18	
293	0.000*
348	0.044
394	0.047*
406	0.010*
414	-0.020
421	-0.046*
437	-0.066*
457	-0.076
500	-0.056*
525	-0.052
549	-0.072*
591	-0.070
609	-0.056*

T	$\Delta L/L_0$
CURVE 18 (cont.)	
624	-0.042
634	-0.040
647	-0.060
665	-0.032*
683	-0.046*
CURVE 19	
293	0.000*
326	0.069
359	0.177
391	0.314
398	0.277
417	0.233
448	0.137
477	0.127
486	0.133
513	0.115
548	-0.121
588	-0.347
605	-0.408
625	-0.449
651	-0.558
674	-1.062
694	-1.302
CURVE 20	
293	0.000*
339	0.134
397	0.314
442	0.115*
475	0.067
504	-0.780
533	-1.228
CURVE 21	
293	0.000*
388	0.314
459	0.126
492	0.076
543	-0.843
CURVE 22	
293	0.000*
363	0.233
406	0.220

T	$\Delta L/L_0$
CURVE 22 (cont.)	
526	-0.034*
541	-0.201
621	-0.387
667	-0.674
691	-1.036
CURVE 23	
293	0.000*
330	0.038
348	0.067*
372	0.090*
456	0.127
498	0.071
537	0.053
620	0.088
666	0.115
CURVE 24	
293	0.000*
310	0.014
338	0.047
427	0.100
565	0.030
638	0.072
669	0.091
680	0.091
CURVE 25	
293	0.000*
350	0.052*
401	0.094*
428	0.086*
451	0.027
477	0.000
502	0.003
558	-0.004
661	0.038
673	0.034
CURVE 26	
293	0.000*
364	0.077*
398	0.099
431	0.079
460	0.090

T	$\Delta L/L_0$
CURVE 26 (cont.)	
516	0.040
559	0.024
618	0.051
673	0.097
CURVE 27	
293	0.000*
330	0.044*
349	0.060*
390	0.094
413	0.097*
430	0.090*
470	0.047
550	0.030
588	0.038
673	0.098*
683	0.094
CURVE 28	
293	0.000*
332	0.050*
351	0.074*
378	0.107
419	0.140
463	0.156*
484	0.140
516	0.090
535	0.074
596	0.097
650	0.140
671	0.142
CURVE 29	
293	0.000*
362	0.080*
445	0.123*
501	0.070
563	0.030*
632	0.070
692	0.107
CURVE 30	
293	0.000*
350	0.050*
396	0.117

T	$\Delta L/L_0$
CURVE 30 (cont.)	
442	0.143*
463	0.137
511	0.054
533	0.047
553	0.054
595	0.074*
673	0.128*
CURVE 31	
296	0.001*
363	0.175
416	0.239*
449	0.427
485	0.883
502	1.078
518	1.233
546	1.088
593	0.659
623	0.592
672	0.661
CURVE 32	
296	0.001*
356	0.155
448	0.365
485	0.899*
508	1.349
559	0.917
616	0.626
639	0.610
675	0.634
CURVE 33	
296	0.001*
338	0.111
420	0.262
424	0.279
503	0.973
521	1.015
539	0.853
575	0.437
630	0.324
648	0.337

* Not shown in figure.

DATA TABLE 447. THERMAL LINEAR EXPANSION OF GRAPHITE FABRIC/PHENOLIC RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 34	
296	0.001*
379	0.191
455	0.455
517	1.272
593	0.619
636	0.539
672	0.576
CURVE 35	
293	0.000*
347	0.033
399	0.072
451	0.129
517	0.171
561	0.198
601	0.154
648	-0.032
688	-0.052
CURVE 36	
293	0.000*
321	0.018
333	0.026
390	0.073
456	0.143
518	0.194
562	0.216
577	0.226
585	0.214
617	0.161
686	0.114
CURVE 37	
293	0.000*
340	0.023
410	0.068
462	0.123*
510	0.156
569	0.196
579	0.197
588	0.100
666	-0.089

T	$\Delta L/L_0$
CURVE 38	
293	0.000*
341	0.031*
402	0.084*
452	0.137*
509	0.174
535	0.194
563	0.219*
597	0.194
672	0.096*
CURVE 39	
293	0.000*
344	0.027*
406	0.073
452	0.123*
506	0.174
541	0.190
559	0.197*
590	0.193
676	0.106
CURVE 40	
293	0.000*
340	0.023*
393	0.060*
461	0.167*
511	0.206
561	0.222*
588	0.235
610	0.196
674	0.153
CURVE 41	
293	0.000*
352	0.030*
393	0.067*
460	0.132*
522	0.169
539	0.171
558	0.167
624	0.078
673	0.045*

T	$\Delta L/L_0$
CURVE 42	
293	0.000*
349	0.036*
449	0.138*
500	0.193
561	0.236*
582	0.237
598	0.214*
666	0.133*
CURVE 43	
293	0.000*
331	0.005
393	0.014
447	0.027
525	0.064
587	0.181
617	0.185*
629	0.175
676	0.122*
CURVE 44	
293	0.000*
328	0.007*
405	0.016*
448	0.025*
518	0.065
561	0.094
585	0.156
613	0.132
671	0.118
CURVE 45	
293	0.000*
338	0.006*
391	0.015*
453	0.027
505	0.056
595	0.104*
622	0.115
648	0.093
681	0.062
CURVE 46	
293	0.000*

T	$\Delta L/L_0$
CURVE 46 (cont.)	
346	0.006
470	0.033*
521	0.061*
585	0.126
599	0.144
616	0.129
678	0.086*

* Not shown in figure.

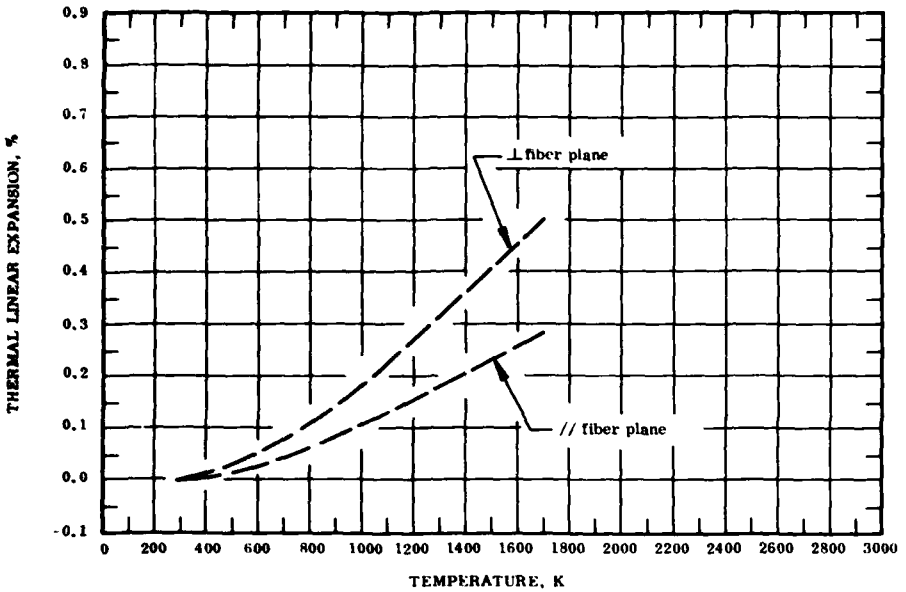
DATA TABLE 447. COEFFICIENT OF THERMAL LINEAR EXPANSION OF GRAPHITE FABRIC/PHENOLIC RESIN COMPOSITE

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 9	
173	11.70
183	13.00
193	13.00
203	13.70
213	13.70
223	14.60
233	15.00
243	15.60
253	17.20
263	16.90
273	17.20
283	16.60
293	16.30
303	13.70*
313	14.30*
323	13.70*
333	12.70*
343	10.70*
353	12.40*
363	11.70*
373	13.70*
383	14.30*
393	16.90*
403	17.20*
413	18.50*
423	21.50*
433	22.80*
443	29.90*
453	40.20*
463	76.10*
473	199.00*
CURVE 10	
173	10.[illegible]
183	12.40*
193	11.40
203	10.20
213	9.00
223	9.90
233	9.30
243	9.60
253	9.90
263	102.00
273	11.50
283	108.00
293	9.30
303	10.50*
313	6.20*
323	6.80*
333	6.20*
343	5.30*
353	5.60*
363	7.40*
373	8.10*
383	6.80*
393	7.40*
403	9.60*
413	13.30*
423	14.20*
433	15.50*
443	13.00*
453	14.20*
463	20.70*
473	22.30*

* Not shown in figure.

FIGURE AND TABLE NO. 446R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/CARBON COMPOSITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

	⊥ fiber plane		// fiber plane	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
293	0.000	0.8	0.000	0.6
400	0.012	1.4	0.003	0.9
500	0.029	2.0	0.013	1.2
600	0.050	2.5	0.029	1.5
700	0.078	3.0	0.047	1.8
800	0.110	3.4	0.066	2.0
900	0.148	3.7	0.087	2.2
1000	0.186	4.0	0.110	2.3
1100	0.229	4.3	0.132	2.4
1200	0.271	4.5	0.157	2.5
1300	0.316	4.6	0.181	2.6
1400	0.361	4.7	0.208	2.6
1500	0.408	4.7	0.233	2.6
1600	0.456	4.7	0.260	2.6
1700	0.502	4.7	0.288	2.6

REMARKS

The provisional values are based on the data for Carbitex 500 (curves 21 to 24) and are considered accurate to within ± 10%. These values are represented approximately by the following equations:

⊥ fiber plane: $\Delta L/L_0 = 0.009 - 1.444 \times 10^{-4}\ T + 4.150 \times 10^{-7}\ T^2 - 9.390 \times 10^{-11}\ T^3$

// fiber plane: $\Delta L/L_0 = -0.003 - 5.923 \times 10^{-5}\ T + 2.217 \times 10^{-7}\ T^2 - 5.097 \times 10^{-11}\ T^3$

The tabulated values for the coefficient of thermal expansion are obtained by differentiating the above equations and are considered accurate to about ± 10%.

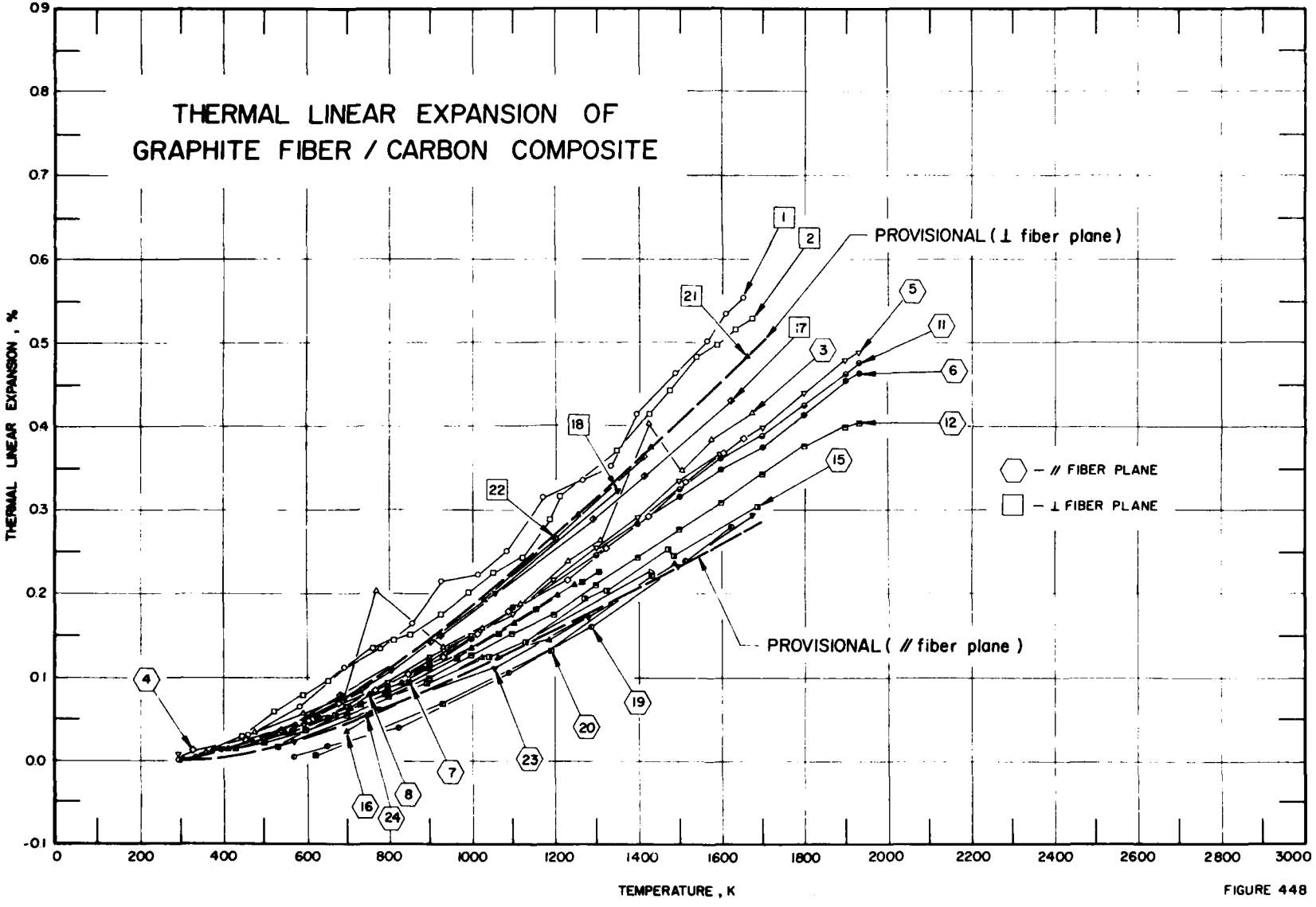

THERMAL LINEAR EXPANSION OF
GRAPHITE FIBER / CARBON COMPOSITE
PROVISIONAL (⊥ fiber plane)
PROVISIONAL (// fiber plane)
⬡ – // FIBER PLANE
□ – ⊥ FIBER PLANE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
1
2
21
17
5
11
3
6
18
12
22
15
4
19
20
23
7
16
8
24

FIGURE 448

SPECIFICATION TABLE 448. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/CARBON COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1078	Roetling, J. and Hanson, J.	1972	L	293-1653	Carbitex 700	Specimen from the Carborundum Co. consisted of graphite base fibers in graphite matrix; fibrous base in the form of square weave fabric which is laid-up in a layered flat construction; density 1.510 g cm^{-3} (manufacturer reports 1.420 g cm^{-3}); measurements across lamina, first run; heating rate 36 F/min.
2	1078	Roetling, J. and Hanson, J.	1972	L	446-1676	Carbitex 700	The above specimen; second run.
3	1078	Roetling, J. and Hanson, J.	1972	L	293-1673	Carbitex 700	Similar to the above specimen; measurements with lamina; heating rate 36 F/min; first run.
4	1078	Roetling, J. and Hanson, J.	1972	L	293-1656	Carbitex 700	The above specimen; second run.
5	1078	Roetling, J. and Hanson, J.	1972	L	293-1934	Carbitex 700	Similar to the above specimen; heating rate 1500 F/min; measurements with lamina.
6	1078	Roetling, J. and Hanson, J.	1972	L	293-1934	Carbitex 700	Similar to the above specimen; heating rate 3000 F/min; measurements with lamina.
7	1078	Roetling, J. and Hanson, J.	1972	L	293-1307	RPP-4	Specimen from LTV Aerospace Corp. in form of flat lay-up construction; density 1.446 g cm^{-3}; measurements with lamina; heating rate 3.6 F/min: first run.
8	1078	Roetling, J. and Hanson, J.	1972	L	293-1250	RPP-4	The above specimen; second run.
9*	1078	Roetling, J. and Hanson, J.	1972	L	293-1283	RPP-4	Similar to the above specimen; measurement across lamina; heating rate 3.6 F/min; first run.
10*	1078	Roetling, J. and Hanson, J.	1972	L	293-1302	RPP-4	The above specimen; second run.
11	1078	Roetling, J. and Hanson, J.	1972	L	293-1932	RPP-4	Similar to the above specimen; measurements with lamina; heating rate 1500 F/min.
12	1078	Roetling, J. and Hanson, J.	1972	L	293-1932	RPP-4	Similar to the above specimen; measurements with lamina; heating rate 3000 F/min.
13*	1079	Naum, R.G., Jun, C.K., and Shaffer, P.T.B.	1972	L	530-1665	Carbitex 700	Specimen from the Carborundum Co.; graphite fibers - cloths, tapes, yarn or chopped fibers bonded together with graphite matrix to form uniformly heterogeneous structure; flat lay-up; density 1.35 g cm^{-3}; sample cut with sample axis perpendicular to fabric plane; first run.
14*	1079	Naum, R.G., et al.	1972	L	562-1443	Carbitex 700	The above specimen; second run.
15	1079	Naum, R.G., et al.	1972	L	327-1689	Carbitex 700	Similar to the above specimen; sample cut with sample axis parallel to fabric plane; first run.
16	1079	Naum, R.G., et al.	1972	L	700-1487	Carbitex 700	The above specimen; second run.
17	1079	Naum, R.G., et al.	1972	L	573-1622	Carbitex 100	The specimen from the Carborundum Co.; carbon fibers - cloths, tapes, yarn or chopped fibers bonded together with carbon matrix to form uniformly heterogeneous structure; flat lay-up; density 1.35 g cm^{-3}; sample cut with sample axis perpendicular to fabric plane; first run.
18	1079	Naum, R.G., et al.	1972	L	626-1352	Carbitex 100	The above specimen; second run.
19	1079	Naum, R.G., et al.	1972	L	574-1625	Carbitex 100	Similar to the above specimen; sample cut with sample axis parallel to fabric plane; first run.
20	1079	Naum, R.G., et al.	1972	L	623-1436	Carbitex 100	The above specimen; second run.

* Not shown in figure.

SPECIFICATION TABLE 448. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/CARBON COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
21	1079	Naum, R.G., Jun, C.K., and Shaffer, P.T.B.	1972	L	572-1661	Carbitex 500	The specimen from the Carborundum Co.; graphite fibers - cloths, tapes, yarn or chopped fibers bonded together with carbon matrix to form uniformly heterogeneous structure; flat lay-up; density 1.40 g cm^{-3}; sample cut with sample axis perpendicular to fabric plane; first run.
22	1079	Naum, R.G., et al.	1972	L	670-1413	Carbitex 500	The above specimen; second run.
23	1079	Naum, R.G., et al.	1972	L	573-1678	Carbitex 500	Similar to the above specimen; sample cut with sample axis parallel to fiber plane; first run.
24	1079	Naum, R.G., et al.	1972	L	751-1434	Carbitex 500	The above specimen; second run.

DATA TABLE 448. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/CARBON COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
293	0.000
338	0.002
461	0.031
586	0.066
694	0.112
780	0.134
859	0.164
930	0.216
1019	0.222
1084	0.251
1175	0.315
1265	0.336
1334	0.354
1399	0.413
1488	0.465
1564	0.501
1608	0.536
1653	0.556
CURVE 2	
446	0.029
525	0.059
598	0.079
657	0.097
761	0.134
814	0.144
855	0.151
927	0.175
994	0.201
1055	0.225
1126	0.243
1190	0.289
1211	0.316
1347	0.371
1425	0.416
1474	0.445
1540	0.485
1591	0.499
1635	0.517
1676	0.530
CURVE 3	
293	0.000*
298	0.000*
360	0.010

T	$\Delta L/L_0$
CURVE 3 (cont.)	
480	0.033
596	0.057
691	0.075
772	0.203
937	0.136
1026	0.159
1119	0.188
1232	0.239
1309	0.263
1423	0.403
1503	0.348
1578	0.384
1673	0.417
CURVE 4	
293	0.000*
298	0.000*
329	0.011
459	0.023
541	0.037
604	0.049
680	0.069
767	0.085
848	0.103
935	0.126
1016	0.152
1090	0.178
1231	0.216
1323	0.254
1422	0.292
1517	0.334
1604	0.369
1656	0.387
CURVE 5	
293	0.000
300	0.000
400	0.012
500	0.026
600	0.045
700	0.065
800	0.094
900	0.123
1000	0.151
1100	0.175

T	$\Delta L/L_0$
CURVE 5 (cont.)	
1200	0.216
1300	0.254
1400	0.290
1500	0.334
1600	0.369
1700	0.399
1800	0.440
1900	0.479
1934	0.489
CURVE 6	
293	0.002*
300	0.000*
400	0.012*
500	0.024*
600	0.044*
700	0.063*
800	0.091
900	0.121
1000	0.149*
1100	0.184
1200	0.216*
1300	0.254*
1400	0.284
1500	0.317
1600	0.350
1700	0.376
1800	0.414
1900	0.457
1934	0.464
CURVE 7	
293	0.000*
433	0.014
567	0.034
657	0.051
734	0.067
792	0.079
853	0.094
966	0.122
1067	0.153
1159	0.181
1266	0.213
1307	0.226

T	$\Delta L/L_0$
CURVE 8	
293	0.000*
417	0.012
552	0.034
633	0.051
703	0.064
756	0.079
834	0.093
900	0.111
1000	0.137
1103	0.165
1207	0.198
1250	0.210
CURVE 9*	
293	0.000
381	0.040
480	0.087
549	0.153
651	0.190
749	0.233
845	0.291
934	0.349
1020	0.407
1111	0.464
1200	0.521
1283	0.581
CURVE 10*	
293	0.000
303	0.000
484	0.071
559	0.131
653	0.184
749	0.239
841	0.295
942	0.350
1031	0.408
1128	0.466
1216	0.523
1302	0.583
CURVE 11	
293	0.000*
300	0.000*

T	$\Delta L/L_0$
CURVE 11 (cont.)	
400	0.014*
500	0.024*
600	0.045*
700	0.066*
800	0.087
900	0.117
1000	0.149
1100	0.181*
1200	0.219*
1300	0.246
1400	0.282*
1500	0.324
1600	0.364
1700	0.389
1800	0.426
1900	0.463
1932	0.478
CURVE 12	
293	0.000*
300	0.000*
400	0.012*
500	0.021
600	0.038
700	0.054
800	0.079
900	0.099
1000	0.127
1100	0.152
1200	0.175
1300	0.210
1400	0.242
1500	0.277
1600	0.309
1700	0.343
1800	0.377
1900	0.400
1932	0.405
CURVE 13*	
530	0.134
674	0.193
937	0.304
1178	0.413
1356	0.513

T	$\Delta L/L_0$
CURVE 13 (cont.)*	
1531	0.605
1665	0.700
CURVE 14*	
562	0.144
737	0.192
1062	0.371
1443	0.561
CURVE 15	
327	0.008
538	0.015
568	0.032
670	0.054
895	0.093
1043	0.125
1131	0.143
1272	0.194
1324	0.204
1473	0.254
1485	0.247
1689	0.304
CURVE 16	
700	0.034
1026	0.124
1185	0.147
1487	0.237
CURVE 17	
573	0.041
681	0.079
924	0.150
1291	0.289
1414	0.340
1622	0.431
CURVE 18	
626	0.052
804	0.109
1060	0.200
1352	0.322

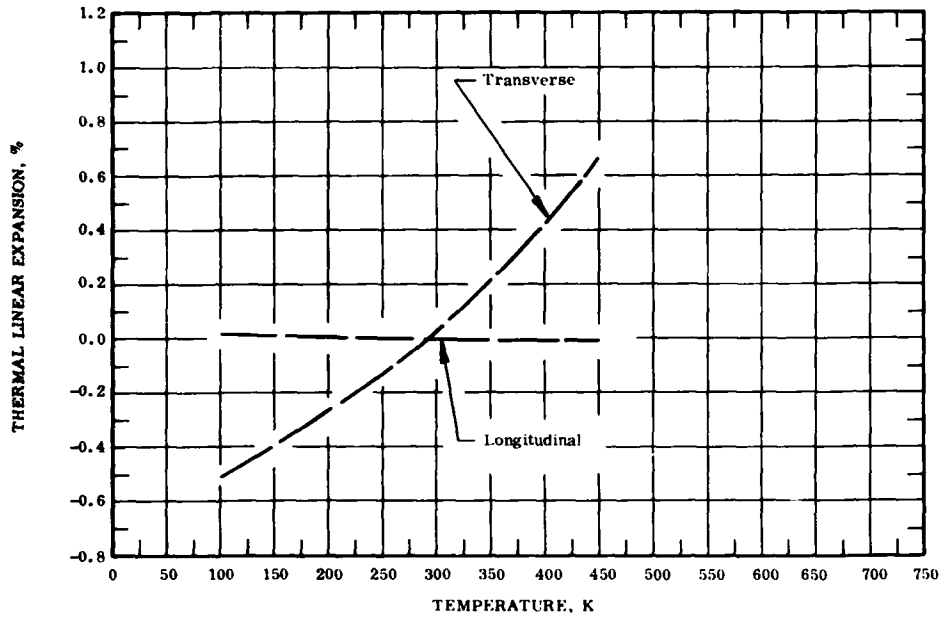
* Not shown in figure.

DATA TABLE 448. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/CARBON COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 19	
574	0.003
651	0.017
826	0.039
1091	0.107
1286	0.160
1515	0.240
1625	0.280
CURVE 20	
623	0.006
932	0.068
1193	0.131
1436	0.221
CURVE 21	
572	0.042*
733	0.083
1033	0.192
1258	0.295
1430	0.375
1661	0.483
CURVE 22	
670	0.057*
901	0.142
1201	0.267
1413	0.365
CURVE 23	
573	0.023
769	0.061
1059	0.111
1280	0.171
1498	0.233
1678	0.294
CURVE 24	
751	0.054
1067	0.123
1434	0.224

* Not shown in figure.

FIGURE AND TABLE NO. 449R. PROVISIONAL VALUES FOR THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE



PROVISIONAL VALUES

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %; α, 10^{-6} K^{-1}]

High Modulus Unidirectional Fibers

	Longitudinal		Transverse	
T	$\Delta L/L_0$	α	$\Delta L/L_0$	α
100	0.0125	-0.8	-0.510	20
125	0.0105	-0.8	-0.455	22
150	0.0087	-0.7	-0.396	23
175	0.0069	-0.7	-0.338	25
200	0.0052	-0.6	-0.272	27
225	0.0037	-0.6	-0.207	28
250	0.0023	-0.5	-0.131	30
275	0.0009	-0.5	-0.054	32
293	0.0000	-0.5	0.000	34
325	-0.0014	-0.4	0.121	37
350	-0.0024	-0.4	0.218	39
375	-0.0032	-0.3	0.320	42
400	-0.0041	-0.3	0.427	44
425	-0.0048	-0.3	0.542	47
450	-0.0055	-0.2	0.660	50

REMARKS

The provisional values for the cured and moisture-free composite with 50-60 volume percent high modulus unidirectional fibers are derived from the data of curves 3-6, 84, 85, and 90 for the longitudinal direction and from the data of curves 7-10, 36, 37, 44, 83, 86, 91, 103 and 106 for the transverse direction. These values are considered accurate to within ± 15% and are represented approximately by the following equations:

Longitudinal: $\Delta L/L_0 = 0.021 - 9.878 \times 10^{-5} T + 8.741 \times 10^{-8} T^2 - 2.171 \times 10^{-12} T^3$

Transverse: $\Delta L/L_0 = -0.688 + 1.584 \times 10^{-3} T + 1.814 \times 10^{-6} T^2 + 2.947 \times 10^{-9} T^3$

The tabulated values for the coefficient of thermal expansion are primarily obtained by differentiating the above equations and are considered accurate to about ± 15%.

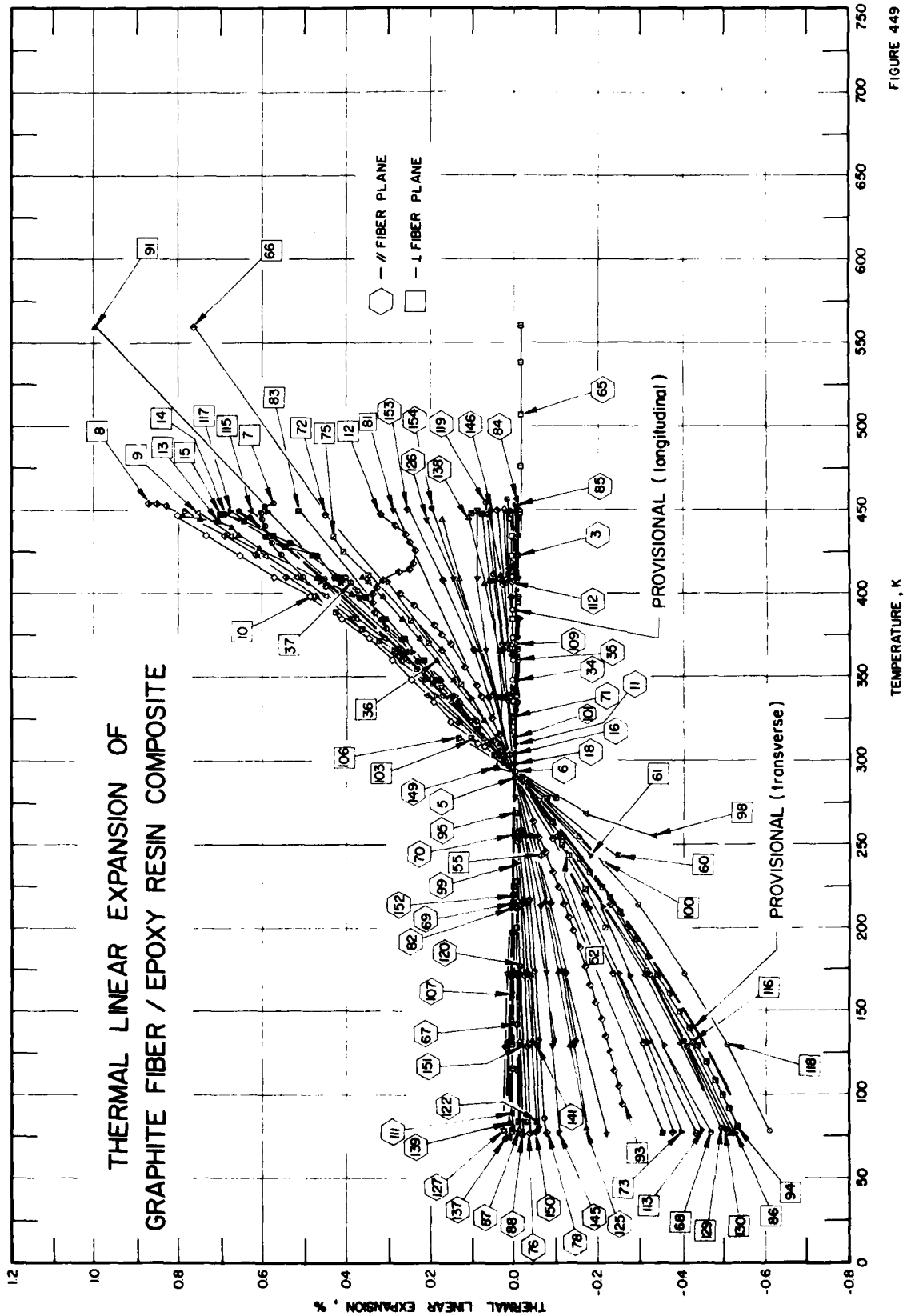

THERMAL LINEAR EXPANSION OF
GRAPHITE FIBER / EPOXY RESIN COMPOSITE
— // FIBER PLANE
— ⊥ FIBER PLANE
PROVISIONAL (longitudinal)
PROVISIONAL (transverse)
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750

FIGURE 449

SPECIFICATION TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1*	1070	Prime, R. B., Barrall, II; E. M., Logan, J. A., and Duke, P. J.	1974		323	Pseudo-random Courtaulds HMS	High modulus graphite fibers/epoxy matrix; six plies $(0 \pm 60)_S$; 45-50 volume % chopped fibers; orientation of composite is 0 deg with respect to surface fibers; measured using thermomechanical analysis technique.
2*	1070	Prime, R. B., et al.	1974		323	Pseudo-random Courtaulds HMS	The above specimen except orientation of composite material is 90 deg with respect to surface fibers.
3	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	289-445	Courtaulds HMS/Hercules 3002 M	High modulus graphite fiber system; density 1.6 g cm^{-3}; fiber tensile modulus 45 x 10^6 psi; composite stiffness 27 x 10^6 psi; six plies of 0 deg (longitudinal) fiber orientation; reinforced epoxy laminates 5 to 7 mil diameter fiber bundles, fiber 50 volume % ; autoclave process provided the final pressure and temperature cycles necessary to cure the resin; expansion in the specimen (and specimens in curves thru 17) measured along length direction for three specimens of single 0.5 x 2 in. laminate roughly 0.050 in. thick; specimen exhibited 0.1-0.3% weight loss; first heating cycle; significant shrinkage observed.
4	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	445-290	Courtaulds HMS/Hercules 3002 M	The above specimen; first cooling cycle; zero-point correction is 0.003%.
5	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	290-445	Courtaulds HMS/Hercules 3002 M	The above specimen except second heating cycle; more stable expansion behavior exhibited during this cycle; zero-point correction is 0.003%.
6	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	445-288	Courtaulds HMS/Hercules 3002 M	The above specimen except second cooling cycle; more stable expansion behavior exhibited during this cycle; zero-point correction is 0.005%.
7	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	293-454	Courtaulds HMS/Hercules 3002 M	High modulus graphite fiber system; density 1.6 g cm^{-3}; fiber tensile modulus 45 x 10^6 psi; composite stiffness 27 x 10^6 psi; eight plies of 90 deg (transverse) orientation; reinforced epoxy laminates 5 to 7 mil diameter fiber bundles; fiber 50 volume %; autoclave process provided the final pressure and temperature cycles necessary to cure the resin; first heating cycle; significant shrinkage observed; specimens exhibited weight loss of 0.1 to 0.3%; zero-point correction is 0.013%.
8	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	454-293	Courtaulds HMS/Hercules 3002 M	The above specimen; first cooling cycle; zero-point correction is 0.312%.
9	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	293-448	Courtaulds HMS/Hercules 3002 M	The above specimen except second heating cycle; more stable expansion behavior exhibited during this cycle; zero-point correction is 0.307%.
10	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	447-293	Courtaulds HMS/Hercules 3002 M	The above specimen except second cooling cycle; more stable expansion behavior exhibited during this cycle; zero-point correction is 0.372%.

* Not shown in figure.

SPECIFICATION TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
11	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	293-447	Courtaulds HMS/Hercules 3002 M	High modulus graphite fiber system; density 1.6 g cm^{-3}; fiber tensile modulus 45 x 10^6 psi; composite stiffness 27 x 10^6 psi; nine plies of balanced symmetric unidirectional-angle ply orientation designated $[0/45/135/0/\overline{90}]_s$; plies stacked in directions (0/+45/-45/0/90/0/-45/+45/0); individual ply thickness 5-8 mils; fiber 50 volume %; autoclave process provided the final pressure and temperature cycles necessary to cure the resin; reported values are for second stable cycle.
12	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	293-447	Modmor II/ Narmco 5206	High strength graphite fiber system; density 1.5 g cm^{-3}; fiber modulus 38 x 10^6 psi; composite strength 161 ksi; eight plies of 90 deg (transverse) orientation; reinforced epoxy laminates 5 to 7 mil diameter fiber bundles; fiber 50 volume %; autoclave process provided the final pressure and temperature cycles necessary to cure the resin; first heating cycle; significant shrinkage observed; zero-point correction is 0.009%.
13	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	447-293	Modmor II/ Narmco 5206	The above specimen; first cooling cycle; zero-point correction is 0.485%.
14	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	293-448	Modmor II/ Narmco 5206	The above specimen except second heating cycle; more stable expansion behavior exhibited during this cycle; zero-point correction is 0.485%.
15	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	448-293	Modmor II/ Narmco 5206	The above specimen except second cooling cycle; more stable expansion behavior exhibited during this cycle; zero-point correction is 0.500%.
16	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	293-449	Modmor II/ Narmco 5206	High strength graphite fiber system; density 1.5 g cm^{-3}; fiber modulus 38 x 10^6 psi; composite strength 161 ksi; six plies of 0 deg (longitudinal) fiber orientation; reinforced epoxy laminates 5 to 7 mil diameter fiber bundles; fiber 50 volume %; autoclave process provided the final pressure and temperature cycles necessary to cure the resin; reported values are for second stable cycle.
17*	1059	Nakamura, H. H. and Larsen, D. C.	1974	L	293-420	Modmor II/ Narmco 5206	High strength graphite fiber system; density 1.5 g cm^{-3}; fiber modulus 38 x 10^6 psi; composite strength 161 ksi; nine plies of balanced symmetric unidirectional-angle ply orientation designated $[0/45/135/0/\overline{90}]_s$; plies stacked in directions (0/+45/-45/0/90/0/-45/+45/0); individual ply thickness 5.8 mils; fiber 50 volume %; autoclave process provided final pressure and temperature cycles necessary to cure the resin; reported values are for second stable cycle.
18	1069	Kalnin, I. L.	1974	L	293-420	GY-70/350 A Laminate	Quasi-isotropic multidirectional laminates made by vacuum/pressure bagging of oriented layups of high modulus (75 x 10^6 psi) UD Celion ^{R} GY-70 graphite tape 7.5 cm wide, prepregged with CRC 350 A resin - a novolac base epoxy/anhydride system; eight plies $[90, 45, 0, -45]_s$; fiber content 60 volume %; cure cycle of 6 hr at 450 K and external pressure of 75 psi; length of the specimen (and specimens in the curves thru 37) is 50 mm; to eliminate nonequilibrium thermal stresses the specimen (and specimens in curves thru 37) cycled 2-3 times between room temperature and 423 K prior to actual measurements; measurements in the principal laminate direction of 0 deg; heating cycle.
19*	1069	Kalnin, I. L.	1974	L	420-293	GY-70/350 A Laminate	The above specimen except cooling cycle.
20*	1069	Kalnin, I. L.	1974	L	293-423	GY-70/350 A Laminate	The above specimen except measurements in the principal laminate direction of 45 deg; heating cycle.

* Not shown in figure.

SPECIFICATION TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
21*	1069	Kalnin, I. L.	1974	L	423-293	GY-70/350 A Laminate	The above specimen except cooling cycle.
22*	1069	Kalnin, I. L.	1974	L	293-423	GY-70/350 A Laminate	The above specimen except measurements in the principal laminate direction of 90 deg; heating cycle.
23*	1069	Kalnin, I. L.	1974	L	423-293	GY-70/350 A Laminate	The above specimen except cooling cycle.
24*	1069	Kalnin, I. L.	1974	L	293-423	GY-70/350 A Laminate	The above specimen except measurements in the principal laminate direction of -45 deg; heating cycle.
25*	1069	Kalnin, I. L.	1974	L	423-293	GY-70/350 A Laminate	The above specimen except cooling cycle.
26*	1069	Kalnin, I. L.	1974	L	293-423	GY-70/350 A Laminate	The above specimen except twelve plies $[+60, 0, -60]_S$ laminate; measurements in the principle laminate direction of 0 deg; average of heating and cooling.
27*	1069	Kalnin, I. L.	1974	L	293-421	GY-70/350 A Laminate	The above specimen except measurements in the principal laminate direction of 30 deg; heating cycle.
28*	1069	Kalnin, I. L.	1974	L	421-293	GY-70/350 A Laminate	The above specimen except cooling cycle.
29*	1069	Kalnin, I. L.	1974	L	293-424	GY-70/350 A Laminate	The above specimen except measurements in the principal laminate direction of 45 deg; heating cycle.
30*	1069	Kalnin, I. L.	1974	L	424-293	GY-70/350 A Laminate	The above specimen except cooling cycle.
31*	1069	Kalnin, I. L.	1974	L	293-424	GY-70/350 A Laminate	The above specimen except measurements in the principal laminate direction of 60 deg; heating cycle.
32*	1069	Kalnin, I. L.	1974	L	424-293	GY-70/350 A Laminate	The above specimen except cooling cycle.
33*	1069	Kalnin, I. L.	1974	L	293-423	GY-70/350 A Laminate	The above specimen except measurements in the principal laminate direction of 90 deg.
34	1069	Kalnin, I. L.	1974	L	293-410	UD GY-70/ 350 A	Composites of density 1.68 g cm^{-3} were made from prepregged GY-70 graphite yarn bundles by the "leaky" pressure molding technique in the form of bars 2.5 cm wide and 25-30 cm long; fiber content 60 ± 1 volume %; void content of < 3% neglected in the calculations; cured panels trimmed, jigged and cut to 0.65 cm strips along those directions in which expansion were to be measured; measurements along axial direction; heating cycle.
35	1069	Kalnin, I. L.	1974	L	410-293	UD GY-70/ 350 A	The above specimen except cooling cycle.
36	1069	Kalnin, I. L.	1974	L	293-410	UD GY-70/ 350 A	The above specimen except measurements along transverse direction; heating cycle.
37	1069	Kalnin, I. L.	1974	L	410-293	UD GY-70/ 350 A	The above specimen except cooling cycle.

* Not shown in figure.

SPECIFICATION TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
38*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type I	Composite made from high modulus carbon fibers and conventional epoxide resin using hardener, diamino diphenyl methane (D. D. M.); final fiber 50 volume %; 1.7 to 6 volume % voids, specimen of 8 x 1.1 x 0.9 cm was cut at an angle 0 deg to the lay of fibers.
39*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type I	Similar to the above specimen except specimen was cut at an angle 10 deg to the lay of fibers.
40*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type I	Similar to the above specimen except specimen was cut at an angle 20 deg to the lay of fibers.
41*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type I	Similar to the above specimen except specimen was cut at an angle 30 deg to the lay of fibers.
42*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type I	Similar to the above specimen except specimen was cut at an angle 45 deg to the lay of fibers.
43*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type I	Similar to the above specimen except specimen was cut at an angle 65 deg to the lay of fibers.
44*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type I	Similar to the above specimen except specimen was cut at an angle 90 deg to the lay of fibers.
45*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type II	Composite made from high strength carbon fibers and conventional epoxide resin using hardener diamino diphenyl methane (D. D. M.); final fiber 50 volume %, 1.7 to 6 volume % voids, specimen of 8 x 1.1 x 0.9 cm was cut at an angle 0 deg to the lay of fibers.
46*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type II	Similar to the above specimen except specimen was cut at an angle 10 deg to the lay of fibers.
47*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type II	Similar to the above specimen except specimen was cut at an angle 20 deg to the lay of fibers.
48*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type II	Similar to the above specimen except specimen was cut at an angle 30 deg to the lay of fibers.
49*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type II	Similar to the above specimen except specimen was cut at an angle 45 deg to the lay of fibers.
50*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type II	Similar to the above specimen except specimen was cut at an angle 65 deg to the lay of fibers.
51*	1071	Knibbs, R. H. and Morris, J. B.	1971	L	353-393	Type II	Similar to the above specimen except specimen was cut at an angle 90 deg to the lay of fibers.
52	1072	Dauksys, R. J.	1973		243-303		Discontinuous graphite fiber modification of epoxy potting compound of density 1.19 g cm^{-3} obtained by mixing chopped Thornel-75 (Union Carbide) continuous yarn (average modulus 83 x 10^6 psi; tensile strength 330 ksi) with epoxy (Epon 815) from Shell; fiber content 5 parts per hundred of epoxy, mixing time 25 min, cured at room temperature for 16 hr before experiments, curing agent diethylene triamine (DTA); rectangular cross section of specimen is 2 x 0.375 x 0.25 in.; average of two runs.
53*	1072	Dauksys, R. J.	1973		243-303		Similar to the above specimen except fiber content 10 parts per hundred of epoxy; density 1.22 g cm^{-3}.

* Not shown in figure.

SPECIFICATION TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
54*	1072	Dauksys, R.J.	1973		243-303		Similar to the above specimen except fiber content 14 parts per hundred of epoxy.
55	1072	Dauksys, R.J.	1973		243-303		Similar to the above specimen except fiber content 16 parts per hundred of epoxy; density 1.23 g cm^{-3}.
56*	1072	Dauksys, R.J.	1973		243-303		Discontinuous graphite modification of epoxy potting compound of density 1.19 g cm^{-3} obtained by mixing chopped Thornel-50 (Union Carbide) continuous yarn with epoxy (Epon 815) from Shell; fiber content 5 parts per hundred of epoxy, mixing time 25 min, cured at room temperature for 16 hr before experiments, curing agent diethylene triamine (DTA); rectangular cross section of specimen 2 x 0.375 x 0.25 in.
57*	1072	Dauksys, R.J.	1973		243-303		Similar to the above specimen except fiber content 10 parts per hundred of epoxy; density 1.19 g cm^{-3}.
58*	1072	Dauksys, R.J.	1973		243-303		Similar to the above specimen except fiber content 14 parts per hundred of epoxy; density 1.18 g cm^{-3}.
59*	1072	Dauksys, R.J.	1973		243-303		Similar to the above specimen except fiber content 16 parts per hundred of epoxy; density 1.18 g cm^{-3}.
60	1072	Dauksys, R.J.	1973		243-303		Discontinuous graphite modification of epoxy potting compound of density 1.17 g cm^{-3} obtained by mixing chopped Thornel-25 (Union Carbide) continuous yarn with epoxy (Epon 815) from Shell; fiber content 5 parts per hundred of epoxy, mixing time 25 min, cured at room temperature for 16 hr before experiments, curing agent diethylene triamine (DTA); rectangular cross section of specimen 2 x 0.375 x 0.25 in.; average of two runs.
61	1072	Dauksys, R.J.	1973		243-303		Similar to the above specimen except fiber content 10 parts per hundred of epoxy; density 1.01 g cm^{-3}.
62*	1072	Dauksys, R.J.	1973		243-303		Similar to the above specimen except fiber content 14 parts per hundred of epoxy; density 1.44 g cm^{-3}.
63*	1072	Dauksys, R.J.	1973		243-303		Similar to the above specimen except fiber content 16 parts per hundred of epoxy; density 1.19 g cm^{-3}.
64*	1072	Dauksys, R.J.	1973		243-303		Discontinuous graphite modification of epoxy potting compound of density 1.16 g cm^{-3} obtained by mixing chopped continuous yarn (designated as VYB-105-1/5) of lower modulus than Thornel yarn with epoxy (Epon 815) from Shell; fiber content 5 parts per hundred of epoxy, mixing time 25 min, cured at room temperature for 16 hr before experiments, curing agent diethylene triamine (DTA); rectangular cross section of specimen 2 x 0.375 x 0.25 in.
65	1073	Freeman, W.T. and Campbell, M.D.	1972	L	78-561	Specimen 4 P13N-T	TRW P13N resin (modulus 0.55 Msi) reinforced with Hercules high tensile (modulus 36.6 Msi) graphite fibers; fiber orientation 0 deg to the top ply; fiber 57.6 volume %; void content 5.3%; specimen stored in dry helium at 297 K for 18 hr (pretest storage environment); shrinkage 1.07 x 10^{-2} % after first high temperature cycle; longitudinal lamina expansion.
66	1073	Freeman, W.T. and Campbell, M.D.	1972	L	78-561	Specimen 5 P13N-T	Similar to the above specimen except fiber orientation 90 deg to the top ply; fiber 57 volume %; void content 5.8%; specimen stored in dry helium at 297 K for 18 hr; shrinkage 13.54 x 10^{-2}% after first high temperature cycle; transverse lamina expansion.
67*	1073	Freeman, W.T. and Campbell, M.D.	1972	L	84-365	Specimen 6 BP907-T	Bloomingdale BP-907 resin (modulus 0.50 Msi) reinforced with Hercules high tensile (modulus 34.9 Msi) graphite fibers; fiber orientation 0 deg to the top ply; fiber 60.2 volume %; void content 0.4%; stored in dry helium at 297 K for 18 hr; shrinkage 0.13 x 10^{-2}% after first high temperature cycle; longitudinal lamina expansion.

* Not shown in figure.

SPECIFICATION TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
68	1073	Freeman, W.T. and Campbell, M.D.	1972	L	297-450	Specimen 7 BP907-T	Similar to the above specimen except fiber orientation 90 deg to the top ply; fiber 60.2 volume %; void content 0.4%; specimen stored in dry helium at 297 K for 18 hr; shrinkage 15.88 x 10^{-2} % after first high temperature cycle; transverse lamina expansion.
69	1073	Freeman, W.T. and Campbell, M.D.	1972	L	79-450	Specimen 8 3002T	Hercules 3002 resin (modulus 0.7 Msi) reinforced with Hercules high tensile (modulus 36.0 Msi) graphite fibers, fiber orientation 0 deg to the top ply; fiber 66.2 volume %; void content 0.0%; to assure constant fiber volume and thickness, small prepreg sheets were laminated with fiber orientation and press cured in the same mold; stored in dry helium at 297 K for 18 hr; shrinkage 1.02 x 10^{-2} % after first high temperature cycle; specimen cycled three times from 297 K to 450 K and final cycle from 297 K to 67 K.
70	1073	Freeman, W.T. and Campbell, M.D.	1972	L	79-450	Specimen 9 3002T	Similar to the above specimen except shrinkage 0.28 x 10^{-2} % after first high temperature cycle.
71	1073	Freeman, W.T. and Campbell, M.D.	1972	S	227-367	Specimen 10 3002T	Similar to the above specimen except stored in 50% relative humidity at 297 K; shrinkage 0.04 x 10^{-2} % after first high temperature cycle.
72	1073	Freeman, W.T. and Campbell, M.D.	1972	L	77-448	Specimen 11 3002T	Similar to the above specimen except fiber orientation 90 deg to the top ply; fiber 65.9 volume %; stored in dry helium at 297 K for 18 hr; cycled three times to 77 K and final to 450 K; shrinkage 3.31 x 10^{-2} % after first high temperature cycle; transverse lamina expansion.
73	1073	Freeman, W.T. and Campbell, M.D.	1972	L	77-448	Specimen 12 3002T	Similar to the above specimen except stored in dry helium at 297 K for 48 hr; cycled three times to 450 K and final to 77 K; shrinkage 7.74 x 10^{-2} % after first high temperature cycle; transverse lamina expansion.
74*	1073	Freeman, W.T. and Campbell, M.D.	1972	L	77-448	Specimen 13 3002T	Similar to the above specimen except specimen stored in vacuum at 297 K for 24 hr; shrinkage 1.43 x 10^{-2} % after first high temperature cycle; transverse lamina expansion.
75	1073	Freeman, W.T. and Campbell, M.D.	1972	S	200-433	Specimen 14 3002T	Similar to the above specimen except stored in 50% relative humidity at 297 K; shrinkage 0.2 x 10^{-2} % after first high temperature cycle; transverse lamina expansion.
76	1073	Freeman, W.T. and Campbell, M.D.	1972	L	77-450	Specimen 15 3002T	Orthotropic laminates prepared from Hercules 3002 resin (modulus 0.70 Msi) with Hercules high tensile (modulus 36.0 Msi) graphite fibers, fiber orientation 0, ±45, 90 deg to the top ply, fiber 65.1 volume %; void content 0.0%; stored in dry helium at 297 K for 98 hr; to assure constant fiber volume and thickness, small prepreg sheets were laminated with fiber orientation and press cured in the same mold; shrinkage 1.27 x 10^{-2} % after first high temperature cycle.
77*	1073	Freeman, W.T. and Campbell, M.D.	1972	L	77-450	Specimen 16 3002T	Similar to the above specimen except fiber orientation 0, 90 deg to the top ply; fiber 65.6 volume %, void content 0.0%; stored in dry helium at 297 K for 72 hr; shrinkage 0.56 x 10^{-2} % after first high temperature cycle.
78	1073	Freeman, W.T. and Campbell, M.D.	1972	S	297-450	Specimen 17 3002T	Similar to the above specimen; stored in 50% relative humidity at 297 K; shrinkage 0.31 x 10^{-2} % after first high temperature cycle.
79*	1073	Freeman, W.T. and Campbell, M.D.	1972	L	297-450	Specimen 18 3002T	Similar to the above specimen except fiber orientation ±30 deg to the top ply; fiber 65 volume %; specimen stored in dry helium at 297 K for 122 hr; shrinkage 0.41 x 10^{-2} % after first high temperature cycle.

* Not shown in figure.

SPECIFICATION TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
80*	1073	Freeman, W.T. and Campbell, M.D.	1972	L	77-450	Specimen 19 3002T	Similar to the above specimen except fiber orientation ±45 deg to the top ply; fiber 65.6 volume %; specimen stored in dry helium at 297 K for 146 hr; shrinkage 1.78×10^{-2} % after first high temperature cycle.
81	1073	Freeman, W.T. and Campbell, M.D.	1972	L	77-450	Specimen 20 3002T	Similar to the above specimen except fiber orientation ±60 deg to the top ply; fiber 65.6 volume %; specimen stored in dry helium at 297 K for 170 hr; shrinkage 4.3×10^{-2} % after first high temperature cycle.
82	1073	Freeman, W.T. and Campbell, M.D.	1972	L	297-450	Specimen 21 3002M	Hercules 3002 resin (modulus 0.70 Msi) reinforced with Hercules high modulus (57.2 Msi) graphite fibers; fiber orientation 0 deg to the top ply, fiber 56.3 volume %, void content 2.4%; stored in dry helium at 297 K for 18 hr; shrinkage 0.56×10^{-2} % after first high temperature cycle; longitudinal lamina expansion.
83	1073	Freeman, W.T. and Campbell, M.D.	1972	L	297-450	Specimen 22 3002M	Similar to the above specimen except fiber orientation 90 deg to the top ply; fiber volume 56.3%, void content 2.4%; stored in dry helium at 297 K for 18 hr; shrinkage 2.83×10^{-2} % after first high temperature cycle.
84	1073	Freeman, W.T. and Campbell, M.D.	1972	L	77-450	Specimen 23 3002M	Similar to the above specimen except fiber orientation 0 deg to the top ply; fiber 49.2 volume %, void content 2.8%; stored in air at 394 K for 40 hr; shrinkage 0.36×10^{-2} % after first high temperature cycle; longitudinal lamina expansion; first run.
85	1073	Freeman, W.T. and Campbell, M.D.	1972	L	77-450	Specimen 23 3002M	Same as the above specimen; second run.
86	1073	Freeman, W.T. and Campbell, M.D.	1972	L	297-450	Specimen 24 3002M	Similar to the above specimen except fiber orientation 90 deg to the top ply; shrinkage 4.30×10^{-2} %.
87	1073	Freeman, W.T. and Campbell, M.D.	1972	L	77-450	Specimen 25 3002M	Similar to the above specimen except fiber orientation of quasi-isotropic laminate 0 ±60 to the top ply; specimen machined along the unidirectional fiber lamina in the plate; fiber 48.6 volume %, void content 3.4%; stored in air at 394 K for 40 hr; shrinkage 0.43×10^{-2} %.
88	1073	Freeman, W.T. and Campbell, M.D.	1972	L	77-450	Specimen 26 3002M	Similar to the above specimen except specimen machined at 15 deg angle clockwise positive to the top unidirectional ply.
89*	1073	Freeman, W.T. and Campbell, M.D.	1972	L	77-408	Specimen 27 3002M	Similar to the above specimen except specimen machined at 30 deg angle clockwise positive to the top unidirectional ply.
90*	1073	Freeman, W.T. and Campbell, M.D.	1972	L	297-450	Specimen 28 BP907M	Bloomingdale BP-907 resin (modulus 0.50 Msi) reinforced with Hercules high modulus (modulus 55.0 Msi) graphite fibers; fiber orientation 0 deg to the top ply; fiber 62.3 volume %; void content 0.0%; stored in desiccant at 297 K for 24 hr; shrinkage 0.10×10^{-2} % after first high temperature cycle; longitudinal lamina expansion.
91	1073	Freeman, W.T. and Campbell, M.D.	1972	L	297-450	Specimen 29 BP970M	Similar to the above specimen except fiber orientation 90 deg to the top ply; shrinkage 3.49×10^{-2} % after first high temperature cycle; transverse lamina expansion.
92*	1074	Pirgon, O., Wostenholm, G.H., and Yates, B.	1973	I			Specimen from test bars of 13 mm^2 cross section, contains 50 volume % carbon fibers Courtaulds HTS carbon fibers, batch PTT 112/212 prepared from polyacrilonitril together with resin ERLA4617 batch B14 hardened with metaphenylene diamine; fibers were assembled in the form of 22 layers of 8 tows per layer; each tow contains 10^4 fibers giving a total of 1.76×10^6 fibers over the cross section of the specimen; cut in a direction perpendicular to the fiber axis; measurements on the similar bar cut parallel to the fiber axis give widely scattered data, so these results were not tabulated.

* Not shown in figure.

SPECIFICATION TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
93	1074	Pirgon, O., Wostenholm, G.H., and Yates, B.	1973	I			Similar to the above specimen except specimen cut 45 deg to the fiber axis.
94	1074	Pirgon, O., et al.	1973	I			Similar to the above specimen except specimen cut perpendicular to the fiber axis.
95	1075	Freund, N.P.	1974		255-338		Manufactured by GD/Convair, ultrahigh modulus Gr/Ep system composed of GY-70 graphite fibers by Celanese Corp., and X-904 epoxy resin by Faberite Corp.; pseudo isotropic lay ups with symmetric configuration $(0/\pm45/90)_S$; measurements parallel to the outer most fiber orientation; average of 2 tests.
96*	1075	Freund, N.P.	1974		255-338		Similar to the above specimen except measurements 90 deg to the outermost fiber orientation.
97*	1075	Freund, N.P.	1974				Similar to the above specimen except measurements at an angle 45 deg to the outermost fiber orientation.
98	1075	Freund, N.P.	1974				Similar to the above specimen except measurements normal to surface.
99	1076	Keller, L.B. and Raech, H.	1974	L			Long fiber molding compound from Fiberite Corp; comprised of bundles of 1 in. long Celanese GY-70 fibers impregnated with proprietary epoxy resin; exposed to seven-day aging at 400 K; zero rebulking observed; test panels were cut from them at 450 K and 1000 psi; cured for 1.5 hr followed by 2 hr post cure at 450 K; fiber content 48.2 volume %; density 1.64 g cm^{-3}; measurements parallel to fibers.
100	1076	Keller, L.B. and Raech, H.	1974	L			Similar to the above specimen; measurements perpendicular to fibers.
101	1077	Goggin, W.R.	1974	L	278-313		Composite from Goodyear Corp. of Akron, Ohio; six plies made of Thornel 75S graphite fibers embedded in ELRB/4617 epoxy resin; nominal composition 37 weight % resin; measurements parallel (in plane) to the fiber orientation.
102*	1077	Goggin, W.R.	1974	L	278-313		The above specimen except measurements after exposure to 77 K.
103*	1077	Goggin, W.R.	1974	L	278-313		Similar to the above specimen except measurements perpendicular to laminate.
104*	1077	Goggin, W.R.	1974	L	278-313		Similar to the above specimen except Modmor 1 graphite fibers used; measurements parallel (in plane) to the fiber orientation.
105*	1077	Goggin, W.R.	1974	L	278-313		The above specimen except measurements after exposure to 77 K; no further changes observed after six additional cycles.
106	1077	Goggin, W.R.	1974	L	278-313		Similar to the above specimen except measurements perpendicular to laminate plane.
107	1060	Hertz, J., Christian, J.L., and Varlas, M.	1972	L	80-450	NO568	Courtaulds HTS/Faberite X-904; expansion for unidirectional lay up in 0 deg direction.
108*	1060	Hertz, J., et al.	1972	L	80-450	NO602	Similar to the above specimen and conditions.
109	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 684	Similar to the above specimen and conditions; panel 1A-39-1.
110*	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 685	Similar to the above specimen and conditions; last stable cycle.
111	1060	Hertz, J., et al.	1972	L	89-450	Specimen No. 715	Similar to the above specimen and condition; specimen water boiled for 24 hr.

* Not shown in figure.

SPECIFICATION TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
112	1060	Hertz, J., Christian, J. L., and Varlas, M.	1972	L	79-450	Specimen No. 716	Similar to the above specimen and conditions.
113	1060	Hertz, J., et al.	1972	L	79-450	NO566	Similar to the one from Curve 107; expansion for unidirectional layup in 90 deg direction; zero-point correction 0.013%.
114*	1060	Hertz, J., et al.	1972	L	79-450	NO567	Similar to the above specimen and conditions; zero-point correction 0.01%.
115	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 692	Similar to the above specimen and conditions; panel 1A-39-1; zero-point correction 0.028%.
116	1060	Hertz, J., et al.	1972	L	76-450	Specimen No. 693	Similar to the above specimen and conditions; zero-point correction 0.02%.
117	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 720	Similar to the above specimen and conditions; last stable cycle; zero-point correction 0.04%.
118	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 718	Similar to the above specimen and conditions; zero-point correction 0.02%.
119	1060	Hertz, J., et al.	1972	L	86-455	NO530	Similar to the above specimen; expansion for $[\pm 45°]_C$ layup in 0 deg direction; zero-point correction 0.003%.
120	1060	Hertz, J., et al.	1972	L	84-457	NO531	Similar to the above specimen and conditions; panel 0C16-C5; zero-point correction 0.001%.
121*	1060	Hertz, J., et al.	1972	L	84-456	NO537	Similar to the above specimen, expansion for $[\pm 45°]_C$ layup in 45 deg direction.
122	1060	Hertz, J., et al.	1972	L	84-452	NO536	Similar to the above specimen and conditions; zero-point correction 0.002%.
123*	1060	Hertz, J., et al.	1972	L	81-450	NO569	Similar to the above specimen and conditions; expansion for $[0_2°/\pm 45°]_S$ in the 0 deg direction.
124*	1060	Hertz, J., et al.	1972	L	81-450	NO570	Similar to the above specimen and conditions.
125	1060	Hertz, J., et al.	1972	L	80-444	NO571	Similar to the above specimen and conditions; expansion for $[0_2°/\pm 45°]_S$ in the 90 deg direction; zero-point correction 0.005%.
126	1060	Hertz, J., et al.	1972	L	80-444	NO572	Similar to the above specimen and conditions.
127	1060	Hertz, J., et al.	1972	L	79-450	NO573	Celanese GY-70/Faberite X-904; expansion for unidirectional lay up in 0 deg direction; zero-point correction -0.002%.
128*	1060	Hertz, J., et al.	1972	L	79-450	NO579	Similar to the above specimen and conditions; zero-point correction -0.001%.
129	1060	Hertz, J., et al.	1972	L	80-450	NO575	Similar to the above specimen and conditions; expansion in the 90 deg direction; zero-point correction 0.022%.
130	1060	Hertz, J., et al.	1972	L	79-446	NO577	Similar to the above specimen and conditions; zero-point correction 0.034%.
131*	1060	Hertz, J., et al.	1972	L	78-450	NO587	Similar to the above specimen and conditions; expansion for $[\pm 45°]_C$ lay up in the 45 deg direction.
132*	1060	Hertz, J., et al.	1972	L	79-449	NO588	Similar to the above specimen and conditions; zero-point correction -0.001%.
133*	1060	Hertz, J., et al.	1972	L	79-449	NO590	Similar to the above specimen and conditions; expansion in 0 deg direction.
134*	1060	Hertz, J., et al.	1972	L	79-452	NO591	Similar to the above specimen and conditions.
135*	1060	Hertz, J., et al.	1972	L	131-450	NO593	Similar to the above specimen and conditions; expansion for $[0_2°/\pm 45°]_S$ in 0 deg direction.

* Not shown in figure.

SPECIFICATION TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
136*	1060	Hertz, J., Christian, J. L., and Varlas, M.	1972	L	76-450	NO597	Similar to the above specimen and conditions.
137	1060	Hertz, J., et al.	1972	L	74-448	NO599	Similar to the above specimen and conditions; expansion in 90 deg direction; zero-point correction 0.001%.
138	1060	Hertz, J., et al.	1972	L	76-446	NO600	Similar to the above specimen and conditions; zero-point correction 0.002%.
139	1060	Hertz, J., et al.	1972	L	83-451	NO538	Celanese GY-70/Courtaulds HM-S/Faberite X-904; panel 0C15-L-CC2; expansion for unidirectional lay up in 0 deg direction.
140*	1060	Hertz, J., et al.	1972	L	83-450	NO539	Similar to the above specimen and conditions.
141	1060	Hertz, J., et al.	1972	L	80-451	NO565	Similar to the above specimen and conditions; expansion in 90 deg direction; zero-point correction 0.002%.
142*	1060	Hertz, J., et al.	1972	L	80-408	NO540	Similar to the above specimen and conditions; zero-point correction -0.001%.
143*	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 709	Similar to the above specimen and conditions; panel 70-HMS-E-2, Batch 1A-13; expansion for unidirectional lay up in 0 deg direction; zero-point correction -0.001%.
144*	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 710	Similar to the above specimen and conditions.
145	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 712	Similar to the above specimen and conditions; expansion in 90 deg direction; zero-point correction 0.02%.
146	1060	Hertz, J., et al.	1972	L	77-450	Specimen No. 713	Similar to the above specimen and conditions; zero-point correction 0.001%.
147*	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 724	Similar to the above specimen and conditions; specimen water boiled for 24 hr; expansion for unidirectional lay up in 0 deg direction; zero-point correction -0.003%.
148*	1060	Hertz, J., et al.	1972	L	89-450	Specimen No. 729	Similar to the above specimen and conditions; zero-point correction -0.001%.
149	1060	Hertz, J., et al.	1972	L	78-448	Specimen No. 726	Similar to the above specimen and conditions; expansion in 90 deg direction; zero-point correction 0.007%.
150	1060	Hertz, J., et al.	1972	L	78-450	Specimen No. 727	Similar to the above specimen and conditions; zero-point correction 0.002%.
151	1060	Hertz, J., et al.	1972	L	80-450	NO630	Good Year random molded HT-S/X-904 laminate; expansion in 0 deg direction.
152	1060	Hertz, J., et al.	1972	L	79-453	NO634	Similar to the above specimen and conditions; zero-point correction -0.001%.
153	1060	Hertz, J., et al.	1972	L	80-451	NO632	Similar to the above specimen; expansion in 30 deg direction; zero-point correction 0.01%.
154	1060	Hertz, J., et al.	1972	L	76-451	NO631	Similar to the above specimen and conditions; zero-point correction 0.005%.

* Not shown in figure.

DATA TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1*	
293	0.000
323	0.008
CURVE 2*	
293	0.000
323	0.008
CURVE 3	
289	0.000
293	0.000
298	0.000
310	0.000
323	-0.001
330	-0.001
335	-0.001
348	-0.002
360	-0.003
367	-0.004
373	-0.004
385	-0.005
398	-0.006
410	-0.007
423	-0.008
435	-0.009
445	-0.010
CURVE 4	
445	-0.006
435	-0.006
423	-0.006
410	-0.005
398	-0.005
385	-0.005
373	-0.005
367	-0.004
360	-0.004
348	-0.003
335	-0.002
323	-0.001
317	-0.001
310	0.000
298	0.000
293	0.000
290	0.000

T	$\Delta L/L_0$
CURVE 5	
290	0.00008
293	0.00000*
298	-0.00009*
310	-0.0005*
317	-0.0008
323	-0.0012
335	-0.0023*
348	-0.0033
353	-0.0037*
360	-0.0042
366	-0.0044*
373	-0.0046*
385	-0.0048*
390	-0.0049
398	-0.0052*
410	-0.0060
423	-0.0070*
435	-0.0079*
445	-0.0087
CURVE 6	
445	-0.0072*
435	-0.0066
423	-0.0058
410	-0.0050*
398	-0.0042*
385	-0.0038
373	-0.0036
367	-0.0035*
360	-0.0033*
348	-0.0028*
335	-0.0021
323	-0.0014*
310	-0.0007*
298	-0.0002*
293	0.00000
288	0.00002*
CURVE 7	
293	0.000*
297	0.013*
310	0.062*
323	0.106*
335	0.156*
348	0.211

T	$\Delta L/L_0$
CURVE 7 (cont.)	
360	0.268
373	0.328*
385	0.384
398	0.446*
410	0.504
423	0.553
431	0.575
435	0.590*
441	0.597
445	0.601
448	0.601
452	0.596
454	0.571
CURVE 8	
454	0.870
454	0.846
452	0.824
448	0.781*
435	0.688
423	0.613
410	0.541
398	0.474
385	0.408*
373	0.344*
360	0.293*
348	0.241*
335	0.185*
323	0.135
310	0.083*
298	0.028*
295	0.011*
293	0.000*
CURVE 9	
293	0.000*
300	0.026
310	0.062
323	0.105
335	0.152
348	0.204
360	0.255
373	0.310
385	0.374
398	0.447

T	$\Delta L/L_0$
CURVE 9 (cont.)	
410	0.519
423	0.594
435	0.674
448	0.752
CURVE 10	
447	0.801
435	0.734
423	0.652
410	0.570
398	0.485
385	0.410
373	0.345
360	0.292
348	0.244
335	0.198
323	0.153
310	0.089
308	0.070
293	0.000
CURVE 11	
293	0.0000*
306	0.0005*
308	0.0006*
310	0.0006
362	0.0022*
363	0.0022*
365	0.0023
416	0.0041*
417	0.0041*
419	0.0042
CURVE 12	
293	0.000*
297	0.013*
306	0.035
312	0.052
323	0.091
335	0.135
348	0.179

T	$\Delta L/L_0$
CURVE 12 (cont.)	
360	0.225*
372	0.277*
379	0.305
385	0.323*
389	0.332
395	0.338
400	0.338
404	0.327
408	0.312
410	0.302*
413	0.377
415	0.251
417	0.242*
418	0.240
423	0.236*
426	0.236
431	0.246
436	0.260
441	0.284
447	0.320
CURVE 13	
447	0.796
445	0.746
443	0.707
440	0.677
435	0.654
427	0.606
423	0.586*
410	0.469
400	0.388
398	0.371*
385	0.314*
373	0.265*
360	0.228*
348	0.185*
335	0.143*
323	0.099*
310	0.057*
297	0.014*
293	0.000*
CURVE 14	
293	0.000*
297	0.014*

T	$\Delta L/L_0$
CURVE 14 (cont.)	
310	0.061*
323	0.102*
335	0.149*
348	0.189
360	0.231
373	0.269
385	0.319
398	0.368
410	0.428
423	0.470
429	0.545
435	0.596
448	0.688
CURVE 15	
448	0.703
443	0.642
435	0.573
431	0.537
423	0.482
410	0.416
398	0.358
385	0.313
373	0.263
360	0.218
348	0.181*
335	0.147*
323	0.104*
310	0.064*
297	0.018*
293	0.000*
CURVE 16	
293	0.0000*
305	-0.0006
307	-0.0007*
309	-0.0008*
361	-0.0066*
363	-0.0068
365	-0.0070*
416	-0.0142
418	-0.0144*
420	-0.0146*
445	-0.0171*
447	-0.0172*
449	-0.0172

* Not shown in figure.

DATA TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 17*	
293	0.0000
307	0.0010
308	0.0011
310	0.0012
362	0.0048
363	0.0049
365	0.0050
417	0.0087
419	0.0088
420	0.0089
CURVE 18	
293	0.0000*
298	0.0003
310	0.0009*
323	0.0016*
335	0.0023*
348	0.0029*
373	0.0043*
398	0.0056
410	0.0063*
420	0.0068*
CURVE 19*	
420	0.0063
410	0.0057
398	0.0051
373	0.0038
348	0.0025
335	0.0018
323	0.0012
310	0.0006
298	0.0001
293	0.0000
CURVE 20*	
293	0.0000
298	0.0002
310	0.0008
323	0.0013
335	0.0018
348	0.0023
373	0.0033
398	0.0044
410	0.0049
423	0.0055

T	$\Delta L/L_0$
CURVE 21*	
423	0.0064
410	0.0059
398	0.0053
373	0.0042
348	0.0032
335	0.0026
323	0.0021
310	0.0015
298	0.0006
293	0.0000
CURVE 22*	
293	0.0000
298	0.0002
310	0.0007
323	0.0010
335	0.0014
348	0.0017
373	0.0023
398	0.0030
410	0.0033
423	0.0036
CURVE 23*	
423	0.0002
410	-0.0001
398	-0.0003
373	-0.0007
348	-0.0008
335	-0.0008
323	-0.0007
310	-0.0006
298	-0.0002
293	0.0000
CURVE 24*	
293	0.0000
298	0.0003
310	0.0008
323	0.0012
335	0.0016
348	0.0021
373	0.0031
398	0.0040
410	0.0045
423	0.0050

T	$\Delta L/L_0$
CURVE 25*	
423	0.0057
410	0.0051
398	0.0047
373	0.0037
348	0.0027
335	0.0022
323	0.0018
310	0.0012
298	0.0004
293	0.0000
CURVE 26	
293	0.0000
298	0.0003
310	0.0008
323	0.0012
335	0.0016
348	0.0021
373	0.0029
398	0.0038
410	0.0043
423	0.0048
CURVE 27*	
293	0.0000
398	0.0003
310	0.0008
323	0.0014
335	0.0018
348	0.0024
373	0.0034
398	0.0044
410	0.0049
421	0.0053
CURVE 28*	
421	0.0043
410	0.0039
398	0.0034
373	0.0025
348	0.0017
335	0.0012
323	0.0009
310	0.0005
298	0.0002
293	0.0000

T	$\Delta L/L_0$
CURVE 29*	
293	0.0000
298	0.0003
310	0.0010
323	0.0015
335	0.0020
348	0.0025
373	0.0035
398	0.0045
410	0.0050
424	0.0065
CURVE 30*	
424	0.0050
410	0.0045
398	0.0040
373	0.0031
348	0.0022
335	0.0017
323	0.0013
310	0.0008
298	0.0002
293	0.0000
CURVE 31*	
293	0.0000
298	0.0002
310	0.0008
323	0.0013
335	0.0018
348	0.0024
373	0.0034
398	0.0055
410	0.0050
424	0.0056
CURVE 32*	
424	0.0053
410	0.0047
398	0.0041
373	0.0030
348	0.0020
335	0.0015
323	0.0010
310	0.0005
298	0.0001
293	0.0000

T	$\Delta L/L_0$
CURVE 33*	
293	0.0000
298	0.0002
310	0.0008
323	0.0014
335	0.0020
348	0.0026
373	0.0038
398	0.0051
410	0.0057
423	0.0063
CURVE 34	
293	0.0000*
298	0.0002*
310	0.0003*
323	-0.0004*
335	-0.0011*
348	-0.0021
360	-0.0030*
373	-0.0041*
385	-0.0051
398	-0.0063*
410	-0.0074
CURVE 35	
410	-0.0108*
398	-0.0096
385	-0.0083*
373	-0.0071*
360	-0.0058
348	-0.0045*
335	-0.0032
323	-0.0018*
310	-0.0003*
298	0.0002*
293	0.0000*
CURVE 36	
293	0.000*
298	0.011*
310	0.038
323	0.072
335	0.106*
348	0.145
360	0.183
373	0.225

T	$\Delta L/L_0$
CURVE 36 (cont.)	
385	0.266
398	0.313
402	0.329*
407	0.348
410	0.361
CURVE 37	
410	0.405
407	0.392
402	0.372
398	0.356*
385	0.305*
373	0.260*
360	0.212*
348	0.170*
335	0.125*
323	0.086*
310	0.047*
298	0.013*
293	0.000*
CURVE 38*, †	
353	0.000
393	-0.005
CURVE 39*, †	
353	0.000
393	0.000
CURVE 40*, †	
353	0.000
393	0.019
CURVE 41*, †	
353	0.000
393	0.043
CURVE 42*, †	
353	0.000
393	0.077

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 43*,†	
353	0.000
393	0.149
CURVE 44*,†	
353	0.000
393	0.231
CURVE 45*,†	
353	0.0000
393	-0.0084
CURVE 46*,†	
353	0.0000
393	-0.0052
CURVE 47*,†	
353	0.0000
393	0.0242
CURVE 48*,†	
353	0.0000
393	0.0474
CURVE 49*,†	
353	0.0000
393	0.1162
CURVE 50*,†	
353	0.0000
393	0.2008
CURVE 51*,†	
353	0.0000
393	0.2456
CURVE 52	
243	-0.128
293	0.000*
303	0.026
CURVE 53*	
243	-0.101
293	0.000
303	0.020
CURVE 54*	
243	-0.082
293	0.000
303	0.016
CURVE 55	
243	-0.061
293	0.000*
303	0.012
CURVE 56*	
243	-0.132
293	0.000
303	0.026
CURVE 57*	
243	-0.096
293	0.000
303	0.020
CURVE 58*	
243	-0.067
293	0.000
303	0.013
CURVE 59*	
243	-0.067
293	0.000
303	0.013
CURVE 60	
243	-0.244
293	0.000*
303	0.049
CURVE 61	
243	-0.180
293	0.000*
303	0.036
CURVE 62*	
243	-0.133
293	0.000
303	0.027
CURVE 63*	
243	-0.111
293	0.000
303	0.022
CURVE 64*	
243	-0.233
293	0.000
303	0.047
CURVE 65	
78	0.0067
116	0.0058
145	0.0050
197	0.0036
225	0.0028
338	-0.0028
365	-0.0050*
395	-0.0080
449	-0.0130
476	-0.0146
507	-0.0154
538	-0.0171
561	-0.0164
CURVE 66	
77	-0.428
297	0.011*
560	0.763
CURVE 67	
84	-0.0032
115	-0.0037
CURVE 67 (cont.)	
142	-0.0037
172	-0.0036
200	-0.0024
227	-0.0024
255	-0.0007*
293	0.0000*
331	0.0002*
365	0.0011*
CURVE 68	
77	-0.463
297	0.019*
450	0.785
CURVE 69	
79	0.0059*
131	0.0052
173	0.0044*
215	0.0036
256	0.0011*
297	-0.0001*
340	-0.0009*
366	-0.0027
408	-0.0041*
450	-0.0051
CURVE 70	
79	0.0079*
131	0.0072*
173	0.0056
215	0.0039*
256	0.0019
297	-0.0001*
340	-0.0010*
367	-0.0022*
409	-0.0038*
450	-0.0055*
CURVE 71	
227	-0.0101*
255	-0.0055
326	0.0043
367	0.0096
CURVE 72	
77	-0.376
131	-0.305
172	-0.236
214	-0.167
254	-0.090
297	0.001*
337	0.103*
366	0.173
407	0.301*
448	0.449
CURVE 73	
77	-0.392
131	-0.317
172	-0.249
212	-0.178
255	-0.090*
337	0.103
366	0.174*
407	0.301
448	0.449*
CURVE 74*	
77	-0.401
131	-0.317
172	-0.249
212	-0.178
255	-0.090
337	0.103
366	0.174
407	0.301
448	0.449
CURVE 75	
200	-0.215
224	-0.166
250	-0.111
289	-0.018
346	0.128
370	0.203
384	0.245
405	0.328*
411	0.349
425	0.404
434	0.430
CURVE 76	
77	-0.0364
129	-0.0277
171	-0.0217
214	-0.0152
252	-0.0076
293	0.0000*
338	0.0082*
365	0.0147*
406	0.0273
450	0.0407
CURVE 77*	
77	-0.0271
130	-0.0212
171	-0.0160
212	-0.0110
252	-0.0059
293	0.0000
338	0.0084
364	0.0148
406	0.0273
450	0.0409
CURVE 78	
77	-0.074
297	0.002*
450	0.045*
CURVE 79*	
77	-0.0388
297	-0.0012
450	-0.0504
CURVE 80*	
77	-0.0345
130	-0.0268
172	-0.0198
214	-0.0140
253	-0.0086
339	0.0071
366	0.0131
407	0.0233
451	0.0349

* Not shown in figure.
† This curve is here reported using the first given temperature as reference temperature at which $\Delta L/L_0 = 0$.

DATA TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 81	
77	-0.218
297	0.007*
450	0.291
CURVE 82	
77	0.0094*
129	0.0085*
171	0.0079
212	0.0055
255	0.0036*
339	-0.0038*
366	-0.0078*
410	-0.0097*
448	-0.0099*
CURVE 83	
77	-0.450
297	0.013*
450	0.517
CURVE 84	
75	0.0121
129	0.0107*
169	0.0085*
213	0.0047*
255	0.0020*
293	0.0000*
341	-0.0011
366	-0.0017*
413	-0.0025
457	-0.0028
CURVE 85	
453	-0.0034
411	-0.0032*
367	-0.0026*
340	0.0018
298	0.0000*
75	0.0122*
CURVE 86	
77	-0.523
297	0.008*
450	0.585

T	$\Delta L/L_0$
CURVE 87	
79	-0.0094
132	-0.0106
174	-0.0081
216	-0.0060
257	-0.0034
297	0.0003*
340	0.0034*
369	0.0061
409	0.0114*
451	0.0214
CURVE 88	
76	-0.0197
131	-0.0168*
172	-0.0134*
214	-0.0084*
256	-0.0045*
293	0.0000*
339	0.0060*
365	0.0101*
409	0.0199
451	0.0263*
451	0.0306*
CURVE 89*	
79	-0.0205
131	-0.0171
171	-0.0129
215	-0.0101
255	-0.0051
293	0.0000
340	0.0055
367	0.0079
409	0.0172
CURVE 90*	
77	0.0109
297	-0.0002
560	-0.0185
CURVE 91	
77	-0.517
297	0.014
560	1.000

T	$\Delta L/L_0$
CURVE 92*	
§	
CURVE 93	
95	-0.257
106	-0.247
115	-0.238
126	-0.227
135	-0.217
146	-0.205
156	-0.193
167	-0.179
177	-0.167
188	-0.153
198	-0.140
207	-0.128
215	-0.116
225	-0.102
234	-0.089
246	-0.072
255	-0.058
265	-0.043
293	0.000*
299	0.009*
309	0.026*
316	0.038
319	0.043*
326	0.056
329	0.062*
338	0.080
345	0.094
347	0.099*
356	0.120
358	0.125*
370	0.157
376	0.175
382	0.195
394	0.240
401	0.271
CURVE 94	
81	-0.529
92	-0.510
100	-0.495
109	-0.478
120	-0.457
130	-0.436
140	-0.414

T	$\Delta L/L_0$
CURVE 94 (cont.)	
150	-0.392
161	-0.366
172	-0.340
183	-0.314
193	-0.290
201	-0.270
210	-0.247
219	-0.223
225	-0.206
234	-0.179
242	-0.155
255	-0.115
264	-0.088
293	0.000*
300	0.023*
311	0.060*
319	0.089
323	0.103*
332	0.137
347	0.199
355	0.236
363	0.275
372	0.322
379	0.361
389	0.424
CURVE 95	
255.2	-0.0005*
269.7	-0.0005
298.0	0.0002*
298.6	0.0002*
299.4	0.0002*
339.0	0.0017*
CURVE 96*	
255.4	-0.0008
268.7	-0.0004
273.2	-0.0004
299.2	0.0001
300.7	0.0001
339.2	0.0002
CURVE 97*	
255.4	-0.0004
269.7	-0.0002
299.2	0.0001

T	$\Delta L/L_0$
CURVE 97 (cont.)*	
300.2	0.0001
339.0	0.0001
CURVE 98	
255.4	-0.330
268.5	-0.170
269.7	-0.170*
296.0	0.010*
299.7	0.030*
300.7	0.030*
339.2	0.209
CURVE 99	
239	-0.0049
277	-0.0014*
311	0.0016*
344	0.0046
CURVE 100	
239	-0.213
277	-0.059
311	0.067
344	0.175
CURVE 101	
278	0.0002
313	-0.0003
CURVE 102*	
278	0.0005
313	-0.0006
CURVE 103*	
278	-0.078
313	0.104
CURVE 104*	
278	-0.0016
313	0.0022

T	$\Delta L/L_0$
CURVE 105*	
278	-0.0011
313	0.0015
CURVE 106	
278	-0.099
313	0.132
CURVE 107	
80	0.0076
133	0.0059
160	0.0043
215	0.0023*
256	-0.0013*
299	-0.0001*
341	-0.0028*
366	-0.0025*
450	-0.0094*
CURVE 108*	
80	0.0081
174	0.0053
215	0.0036
256	0.0016
300	-0.0001
366	-0.0024
410	-0.0028
450	-0.0035
CURVE 109	
78	0.0023*
133	0.0023*
174	0.0024*
215	0.0022*
255	0.0008*
298	0.0000*
339	-0.0006*
370	-0.0006
409	0.0023*
450	0.0058
CURVE 110*	
78	0.0023
131	0.0016
174	0.0011

* Not shown in figure.
§ No experimental data tabulated, see Specification Table.

DATA TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 110 (cont.)*	
215	0.0006
255	0.0002
298	0.0000
340	-0.0007
366	-0.0018
409	-0.0028
450	0.0014
CURVE 111	
89	0.0031
131	0.0043*
173	0.0025*
215	0.0024*
255	0.0012*
299	0.0000*
340	-0.0012*
366	-0.0015*
409	-0.0007*
450	0.0015*
CURVE 112	
79	0.0023*
130	0.0024*
171	0.0036*
214	0.0016*
255	0.0007*
297	0.0000*
338	-0.0002*
367	0.0000*
407	0.0005
450	0.0023*
CURVE 113	
79	-0.4430
130	-0.3574
171	-0.2760
213	-0.2080
255	-0.1067*
298	0.0149*
338	0.1424
365	0.2429
407	0.4130
450	0.5859*

T	$\Delta L/L_0$
CURVE 114*	
79	-0.4388
130	-0.3484
171	-0.2790
213	-0.2041
255	-0.0966
298	0.0119
338	0.1474
365	0.2464
407	0.4100
450	0.5831
CURVE 115	
78	-0.472*
131	-0.396
171	-0.308
214	-0.207*
255	-0.094*
298	0.015*
339	0.154
366	0.259
409	0.435*
450	0.625
CURVE 116	
76	-0.521*
131	-0.421
172	-0.337*
214	-0.229
255	-0.111*
297	0.014*
339	0.159*
366	0.266*
409	0.435*
450	0.635*
CURVE 117	
78	-0.534*
130	-0.423*
172	-0.341*
214	-0.226*
255	-0.108*
297	0.040*
339	0.188
366	0.284
408	0.462
450	0.674

T	$\Delta L/L_0$
CURVE 118	
78	-0.605
130	-0.504
172	-0.402
214	-0.294
255	-0.154
297	0.020*
339	0.171
366	0.279
408	0.453
450	0.657
CURVE 119	
86	-0.0712
133	-0.0580
174	-0.0460
217	-0.0335
258	-0.0165
301	-0.0006*
336	0.0147
370	0.0294
412	0.0483
455	0.0673
CURVE 120	
84	-0.0240
131	-0.0169*
176	-0.0126
216	-0.0082*
257	-0.0043*
300	0.0010*
334	0.0060*
369	0.0091*
411	0.0125*
457	0.0179
CURVE 121*	
84	-0.0223
131	-0.0171
173	-0.0117
215	-0.0080
257	-0.0039
300	0.0000
334	0.0042
369	0.0066
411	0.0109
456	0.0146

T	$\Delta L/L_0$
CURVE 122	
84	-0.0515
132	-0.0401
174	-0.0303
217	-0.0214
258	-0.0114*
336	0.0094*
370	0.0159
411	0.0281
452	0.0408*
CURVE 123*	
81	0.0080
132	0.0069
173	0.0068
215	0.0048
255	0.0029
298	0.0000
339	-0.0022
366	-0.0038
407	-0.0064
450	-0.0095
CURVE 124*	
81	0.0010
130	0.0013
171	0.0020
212	0.0008
254	0.0001
298	0.0000
336	-0.0011
364	-0.0019
406	-0.0041
450	-0.0067
CURVE 125	
80	-0.169
130	-0.134
173	-0.104
216	-0.071
255	-0.035
299	0.006*
340	0.050
366	0.083
409	0.132
444	0.172

T	$\Delta L/L_0$
CURVE 126	
80	-0.175*
130	-0.141
174	-0.109
216	-0.076*
255	-0.042
299	0.006*
340	0.056*
366	0.091*
409	0.145
444	0.208
CURVE 127	
79	0.0250
129	0.0214
172	0.0175
213	0.0123*
254	0.0065*
298	0.0019*
339	-0.0025*
366	-0.0041*
408	-0.0061*
450	-0.0123*
CURVE 128*	
79	0.0205
130	0.0181
173	0.0138
214	0.0087
255	0.0041
298	-0.0019
340	-0.0050
366	-0.0071
408	-0.0100
450	-0.0156
CURVE 129	
80	-0.491
132	-0.400
174	-0.314
214	-0.213*
255	-0.100
299	0.018*
340	0.173*
367	0.289*
408	0.463*
450	0.653*

T	$\Delta L/L_0$
CURVE 130	
79	-0.501
129	-0.410
172	-0.321
213	-0.212*
254	-0.100*
296	0.031*
338	0.175*
364	0.288*
405	0.448
446	0.628
CURVE 131*	
78	-0.0036
130	-0.0026
173	-0.0020
229	-0.0025
258	-0.0014
302	0.0001
340	0.0025
368	0.0047
409	0.0069
450	0.0094
CURVE 132*	
79	0.0150
131	0.0122
174	0.0092
214	0.0060
255	0.0023
299	-0.0005
339	-0.0046
367	-0.0066
409	-0.0094
449	-0.0120
CURVE 133*	
79	0.0180
131	0.0145
174	0.0115
214	0.0080
255	0.0041
299	0.0000
339	-0.0042
367	-0.0059
409	-0.0085
449	-0.0113

* Not shown in figure.

DATA TABLE 449. THERMAL LINEAR EXPANSION OF GRAPHITE FIBER/EPOXY RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 134*	
79	0.0012
131	0.0009
173	0.0013
229	0.0005
259	-0.0003
302	0.0001
341	0.0002
369	0.0006
411	0.0013
452	0.0025
CURVE 135*	
131	0.0197
173	0.0153
215	0.0091
255	0.0043
340	-0.0050
366	-0.0072
409	-0.0114
450	-0.0155
CURVE 136*	
76	0.0187
131	0.0136
173	0.0117
215	0.0066
255	0.0026
297	0.0000
340	-0.0045
366	-0.0063
409	-0.0104
450	-0.0135
CURVE 137	
74	0.021
128	0.020*
170	0.012*
212	-0.002
255	-0.012*
296	0.001*
338	0.005*
366	0.011*
408	0.029
448	0.062

T	$\Delta L/L_0$
CURVE 138	
76	-0.042*
130	-0.035*
171	-0.028*
214	-0.019*
255	-0.011*
296	0.002*
336	0.020*
366	0.036
406	0.066
446	0.107
CURVE 139	
83	0.0125
131	0.0113*
174	0.0087*
215	0.0051*
256	0.0021*
300	-0.0000*
335	-0.0015*
366	-0.0040*
408	-0.0050*
451	-0.0084*
CURVE 140*	
83	0.0135
130	0.0118
173	0.0101
215	0.0058
256	0.0031
300	0.0001
366	-0.0034
408	-0.0055
450	-0.0096
CURVE 141	
80	-0.059
130	-0.048
173	-0.0409*
214	-0.0254
255	-0.0117*
298	0.002*
340	0.0085*
369	0.0200*
410	0.0352*
451	0.0417*

T	$\Delta L/L_0$
CURVE 142*	
83	0.0185
130	0.0124
171	0.0083
214	0.0057
254	0.0026
298	-0.0010
333	0.0017
366	-0.0010
408	-0.0010
CURVE 143*	
78	0.0121
130	0.0099
173	0.0084
214	0.0054
255	0.0013
296	-0.0010
339	-0.0028
366	-0.0041
406	-0.0067
450	-0.0063
CURVE 144*	
78	0.0113
131	0.0101
159	0.0084
214	0.0052
255	0.0019
298	-0.0010
339	-0.0028
366	-0.0039
409	-0.0063
450	-0.0063
CURVE 145	
78	-0.103
130	-0.090
173	-0.077
213	-0.063
255	-0.044*
296	0.020*
340	0.052*
366	0.066
409	0.088
450	0.087

T	$\Delta L/L_0$
CURVE 146	
77	-0.0420*
130	-0.0290*
172	-0.0217*
214	-0.0129*
255	-0.0046*
297	0.0010*
339	0.0182
366	0.0278
408	0.0439
450	0.0538
CURVE 147*	
78	0.0127
130	0.0110
172	0.0082
214	0.0051
255	0.0011
297	-0.0030
339	-0.0054
366	-0.0065
408	-0.0086
450	-0.0091
CURVE 148*	
89	0.0131
130	0.0100
172	0.0075
214	0.0046
255	0.0025
297	-0.0010
339	-0.0040
366	-0.0062
408	-0.0079
450	-0.0106
CURVE 149	
78	-0.0260*
132	-0.0187*
174	-0.0137*
214	-0.0074*
255	-0.0017*
296	0.0070*
296	0.0439
338	0.0265
366	0.0368*

T	$\Delta L/L_0$
CURVE 149 (cont.)	
408	0.0589
448	0.0764
448	0.1058
CURVE 150	
78	-0.0515
130	-0.0465*
172	-0.0365
214	-0.0230*
255	-0.0111*
297	0.0020*
339	0.0136*
366	0.0345*
450	0.0631*
450	0.0814*
CURVE 151	
80	-0.0053*
130	-0.0100
173	-0.0154*
216	-0.0129*
255	-0.0060*
300	0.0000*
340	0.0028*
368	0.0093*
412	0.0177
450	0.0219*
CURVE 152	
79	0.025*
131	0.017
173	0.010*
220	0.002
255	0.002*
300	-0.001*
340	-0.001*
366	-0.002*
411	-0.001*
453	0.000*
CURVE 153	
80	-0.164*
132	-0.142
173	-0.120

T	$\Delta L/L_0$
CURVE 153 (cont.)	
215	-0.083
255	-0.042*
298	0.011*
338	0.062
366	0.100
408	0.169
451	0.257
CURVE 154	
76	-0.110*
132	-0.095
173	-0.077*
215	-0.055*
255	-0.026
298	0.003*
338	0.041
366	0.069*
409	0.124*
451	0.199

* Not shown in figure.

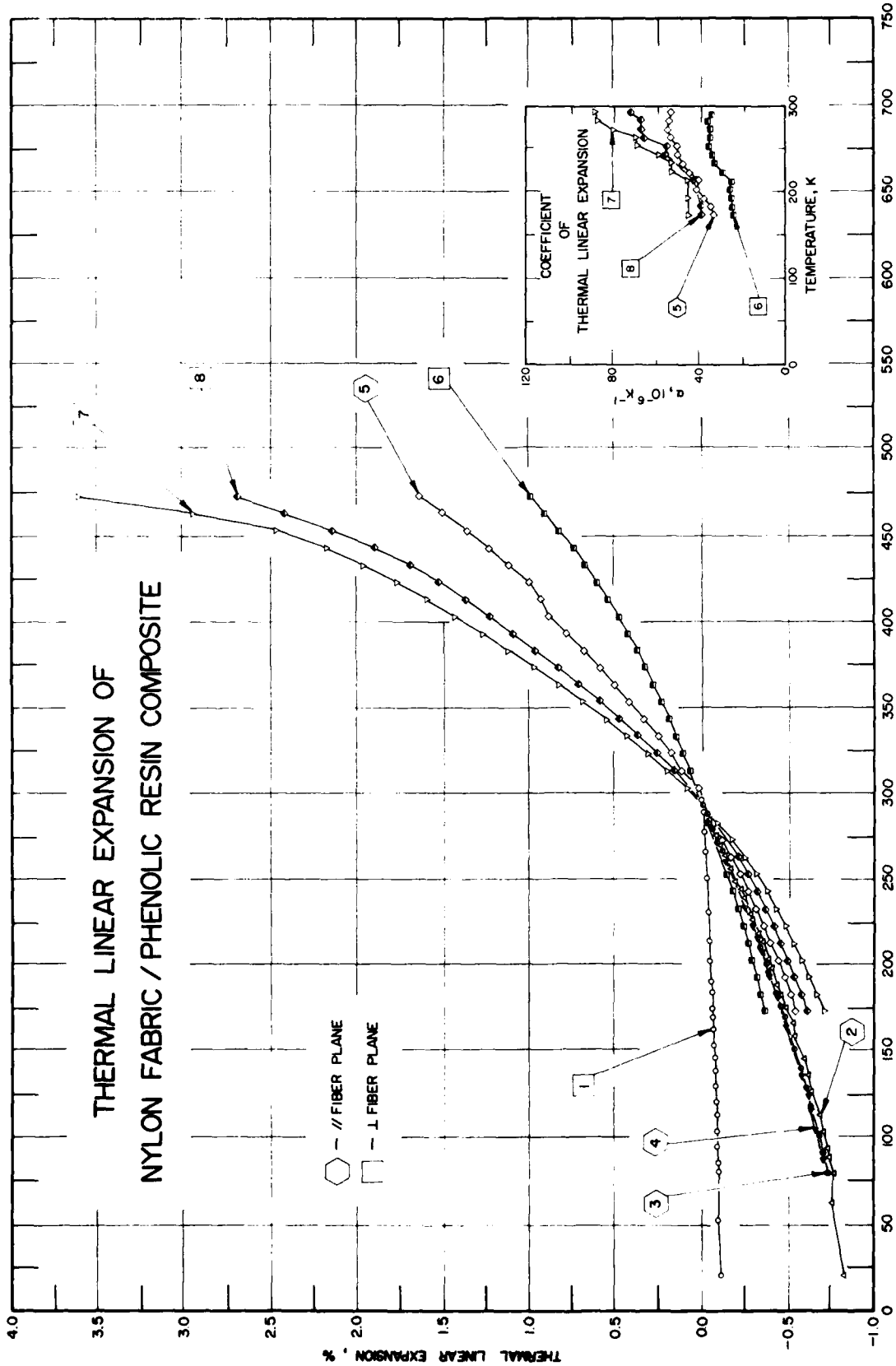

THERMAL LINEAR EXPANSION OF
NYLON FABRIC / PHENOLIC RESIN COMPOSITE
// FIBER PLANE
⊥ FIBER PLANE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K
COEFFICIENT OF THERMAL LINEAR EXPANSION
α , 10⁻⁶ K⁻¹
TEMPERATURE , K

FIGURE 450

SPECIFICATION TABLE 450. THERMAL LINEAR EXPANSION OF NYLON FABRIC/PHENOLIC RESIN COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	574	Haskins, J. F., Campbell, M. D., Hertz, J., and Percy, J. L.	1964	L	20-297		58.0 SN-19 nylon, style YN-25, heat set and scoured finish; impregnated with 42.0 CTL-91-LD phenolic resin; the reinforced chopped nylon laid parallel to the surface with random orientation in the other two directions; a series of 0.5 in. wide pieces, cut in the thickness direction from panel of 10 in. x 0.5 in. x 14 in., stacked end to end and bonded to form specimen of 0.117 in. x 0.117 in. x 2.0 in. (max.); expansion measured in the thickness direction; first run.
2	574	Haskins, J. F., et al.	1964	L	20-298		Similar to the above specimen; sample cut from panel of 4.5 in. x 0.125 in. x 7 in.; expansion measured normal to the thickness direction; first run.
3	574	Haskins, J. F., et al.	1964	L	79-298		Similar to the above specimen; another sample; first run.
4	574	Haskins, J. F., et al.	1964	L	78-292		Similar to the above specimen; immediately cycled after first run; fourth cycle.
5	171	Asay, J. R.	1968		173-473		Chopped nylon phenolic; nylon fabric sheet material on which was impregnated phenolic thermosetting resin binder; consolidated under high temperature and pressure; density 1.68 g cm^{-3}; decomposition begins at 653 K; expansion measured parallel to cloth.
6	171	Asay, J. R.	1968		173-473		The above specimen; expansion measured perpendicular to cloth.
7	171	Asay, J. R.	1968		173-473		Tape-wound nylon phenolic; nylon fibers to form cloth used; density 1.21 g cm^{-3}; expansion measured parallel to axis.
8	171	Asay, J. R.	1968		173-473		The above specimen; expansion measured perpendicular to axis.
9	1056	Wilson, R. G.	1965	L	142-473		50% Union Carbide Bakelite BRP-5549 phenolic resin and 50% DuPont Zytel 103 nylon powder; mixed, hot pressed under vacuum at 700 psi and 433 K for 2 hr; cooled in the mold; post cured in stages to 422 K for 10 hr; high density specimen; data averaged by author from 4 specimens.
10	1056	Wilson, R. G.	1965	L	140-428		25% Union Carbide Bakelite BRP-5549 phenolic resin; 25% Union Carbide phenolic Microballoons (BJO-0930); 50% DuPont Zytel 103 nylon powder; hot-pressed and heat treated as the above specimen; low density specimen; specimen No. 1.
11	1056	Wilson, R. G.	1965	L	146-412		Similar to the above specimen; specimen 3.
12	1056	Wilson, R. G.	1965	L	77-616		Similar to the above specimen; specimen 1.
13	1056	Wilson, R. G.	1965	L	77-632		Similar to the above specimen; specimen 2.
14	1056	Wilson, R. G.	1965	L	77-626		Similar to the above specimen; specimen 3.
15	1056	Wilson, R. G.	1965	L	293-647		Similar to the above specimen; specimen 4.

DATA TABLE 450. THERMAL LINEAR EXPANSION OF NYLON FABRIC/PHENOLIC RESIN COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
20	-0.106
52	-0.098
80	-0.092
85	-0.090
95	-0.088
104	-0.086
113	-0.084
121	-0.081
130	-0.078
139	-0.075
147	-0.072
154	-0.069
163	-0.066
170	-0.063
175	-0.061
179	-0.059*
185	-0.057
191	-0.054
197	-0.052*
203	-0.049
207	-0.046*
215	-0.043
220	-0.040*
228	-0.037*
232	-0.035
239	-0.031*
244	-0.028*
251	-0.025
256	-0.022*
263	-0.018*
267	-0.015
273	-0.012*
278	-0.009
282	-0.006*
290	-0.002
297	0.002

CURVE 2

T	$\Delta L/L_0$
20	-0.825
62	-0.754
79	-0.767
88	-0.749
94	-0.733
103	-0.708
113	-0.685
127	-0.648

CURVE 2 (cont.)

T	$\Delta L/L_0$
136	-0.622
145	-0.594
159	-0.546
166	-0.528
175	-0.490
183	-0.460
189	-0.440
198	-0.405
204	-0.385
214	-0.351
219	-0.327
227	-0.297
230	-0.276
239	-0.245
244	-0.221
249	-0.194
256	-0.167
264	-0.129
270	-0.103
276	-0.079
285	-0.042
288	-0.026*
289	-0.012*
295	-0.010*
298	0.014*

CURVE 3

T	$\Delta L/L_0$
79	-0.729
83	-0.723*
91	-0.705
101	-0.682
109	-0.660*
118	-0.636
129	-0.610
140	-0.577
151	-0.545
159	-0.521*
170	-0.487
176	-0.468
184	-0.438
189	-0.418*
197	-0.392
201	-0.373
211	-0.342
218	-0.319*
225	-0.290*

CURVE 3 (cont.)

T	$\Delta L/L_0$
231	-0.263*
239	-0.232*
244	-0.213*
250	-0.194*
256	-0.168*
263	-0.137*
267	-0.116
272	-0.094
280	-0.060
285	-0.035*
288	-0.027
293	0.000
298	0.013*

CURVE 4

T	$\Delta L/L_0$
78	-0.722*
87	-0.702
105	-0.662
116	-0.638
124	-0.620
136	-0.588
142	-0.561*
152	-0.531*
164	-0.499
168	-0.485*
175	-0.459*
181	-0.440
188	-0.414*
193	-0.396
203	-0.369*
208	-0.346
216	-0.317
223	-0.294
229	-0.271*
234	-0.249
240	-0.224*
248	-0.196*
255	-0.164*
261	-0.139
265	-0.117*
274	-0.094*
278	-0.069*
286	-0.034*
292	-0.006

CURVE 5‡

T	$\Delta L/L_0$
173	-0.548
183	-0.515
193	-0.479
203	-0.440
213	-0.399
223	-0.357
233	-0.311
243	-0.262
253	-0.212
263	-0.161
273	-0.107
283	-0.053*
293	0.000*
303	0.055
313	0.116
323	0.186
333	0.262
343	0.341
353	0.423
363	0.508
373	0.597
383	0.688
393	0.782
403	0.881
413	0.938
423	1.000
433	1.117
443	1.239
453	1.368
463	1.504
473	1.646

CURVE 6‡

T	$\Delta L/L_0$
173	-0.361
183	-0.337
193	-0.313
203	-0.288
213	-0.263
223	-0.236
233	-0.206
243	-0.173
253	-0.139
263	-0.104*
273	-0.070*
283	-0.035
293	0.000

CURVE 6 (cont.)‡

T	$\Delta L/L_0$
303	0.035*
313	0.072
323	0.112
333	0.153
343	0.197
353	0.240
363	0.284
373	0.330
383	0.376
393	0.427
403	0.483
413	0.543
423	0.607
433	0.676
443	0.749
453	0.827
463	0.910
473	0.998

CURVE 7‡

T	$\Delta L/L_0$
173	-0.715
183	-0.669
193	-0.624
203	-0.579
213	-0.533
223	-0.484
233	-0.432
243	-0.377
253	-0.314
263	-0.245
273	-0.171
283	-0.087
293	0.000*
303	0.095
313	0.201
323	0.315
333	0.434
343	0.558
353	0.690
363	0.829
373	0.973
383	1.121
393	1.273
403	1.431
413	1.595
423	1.770

CURVE 7 (cont.)‡

T	$\Delta L/L_0$
433	1.956
443	2.171
453	2.461
463	2.947
473	3.601

CURVE 8‡

T	$\Delta L/L_0$
173	-0.616
183	-0.577
193	-0.538
203	-0.498
213	-0.458
223	-0.414
233	-0.369
243	-0.318
253	-0.263
263	-0.202
273	-0.136*
283	-0.069*
293	0.000*
303	0.077*
313	0.167
323	0.266
333	0.371
343	0.481
353	0.596
363	0.714
373	0.837
383	0.965
393	1.097
403	1.232
413	1.373
423	1.523
433	1.692
443	1.899
453	2.148
463	2.415
473	2.687

CURVE 9

T	$\Delta L/L_0$
142	-0.670
144	-0.678*
172	-0.586
172	-0.554*
199	-0.474

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 450. THERMAL LINEAR EXPANSION OF NYLON FABRIC/PHENOLIC RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 9 (cont.)	
204	-0.439*
222	-0.374*
228	-0.329
255	-0.230*
255	-0.210*
272	-0.132*
273	-0.117*
293	0.000*
297	0.038*
299	0.035
312	0.136*
333	0.278*
372	0.735
372	0.776
393	1.028
413	1.263
432	1.412
432	1.495
453	1.757
463	1.846
473	1.948
CURVE 10	
140	-0.620
172	-0.527*
195	-0.439
220	-0.357
238	-0.280
249	-0.240
270	-0.129
293	-0.011*
296	0.000*
310	0.068
370	0.401
410	0.631
428	0.721
CURVE 11	
146	-0.574*
172	-0.502*
195	-0.412*
222	-0.317*
250	-0.200*
288	-0.029*
293	0.000*
296	0.011
302	0.061

T	$\Delta L/L_0$
CURVE 11 (cont.)	
322	0.185*
332	0.192
343	0.243
361	0.411
412	0.692
CURVE 12	
77	-0.752
102	-0.676*
148	-0.538
183	-0.437*
196	-0.398*
214	-0.338*
273	-0.075*
282	-0.064*
293	0.000*
298	0.016*
339	0.295
393	0.591
460	0.537
504	0.455
563	0.222
616	-0.259
CURVE 13	
77	-0.794*
157	-0.538
196	-0.415*
218	-0.319*
263	-0.165*
281	-0.060*
293	0.000*
352	0.456
405	0.712
453	0.478
515	0.557
573	0.319
632	-0.858
CURVE 14	
77	-0.774*
127	-0.670
150	-0.590
171	-0.507*
196	-0.418*
243	-0.261*

T	$\Delta L/L_0$
CURVE 14 (cont.)	
277	-0.103
293	0.000*
298	0.016*
315	0.104*
339	0.253
366	0.462
393	0.487
429	0.529
439	0.552
464	0.668
493	0.682
516	0.679
538	0.624
586	0.416
616	0.086
626	-0.033
CURVE 15	
293	0.000*
311	0.070*
330	0.192
337	0.206
351	0.219
366	0.249
390	0.314
422	0.363
448	0.363
467	0.382
521	0.406
540	0.340
559	0.240
581	0.037
616	-0.180
631	-0.331
647	-0.682

* Not shown in figure.

DATA TABLE 450. COEFFICIENT OF THERMAL LINEAR EXPANSION OF NYLON FABRIC/PHENOLIC RESIN COMPOSITE

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 5	
173	33.20
183	34.00
193	37.80
203	40.90
213	40.00
223	44.20
233	47.70
243	49.70
253	50.10
263	53.20
273	54.10
283	53.80
293	52.70
303	58.00*
313	64.20*
323	74.30*
333	78.00*
343	80.00*
353	84.20*
363	86.60*
373	89.80*
383	92.30*
393	96.30*
403	102.20*
413	110.79*
423	113.80*
433	119.80*
443	125.60*
453	132.00*
463	139.60*
473	144.00*
CURVE 6	
173	24.00
183	24.40
193	24.30
203	25.60
213	24.60
223	28.80
233	32.20
243	33.30
253	35.00
263	34.30
273	34.30
283	35.70
293	34.00

T	α
CURVE 6 (cont.)	
303	36.00*
313	38.80*
323	39.80*
333	43.00*
343	44.00*
353	43.30*
363	44.80*
373	46.10*
383	47.10*
393	54.00*
403	59.20*
413	59.90*
423	68.90*
433	68.20*
443	76.90*
453	79.70*
463	86.30*
473	90.10*
CURVE 7	
173	45.40
183	45.40
193	45.40
203	45.40
213	45.40
223	52.10
233	52.10
243	58.40
253	68.40
263	68.80
273	79.90
283	86.70
293	88.10
303	102.10*
313	109.50*
323	118.20*
333	120.40*
343	128.00*
353	136.50*
363	140.70*
373	147.40*
383	148.90*
393	155.50*
403	159.20*
413	169.20*
423	181.20*

T	α
CURVE 7 (cont.)	
433	190.10*
443	239.70*
453	340.10*
463	633.50*
473	674.20*
CURVE 8	
173	39.00
183	39.00
193	39.20*
203	39.50*
213	42.00
223	44.20*
233	46.20*
243	55.70
253	55.10
263	65.80
273	66.80
283	66.80
293	71.90
303	82.60*
313	96.70*
323	102.10*
333	108.20*
343	111.90*
353	116.90*
363	119.60*
373	126.30*
383	130.00*
393	133.00*
403	138.00*
413	143.40*
423	155.90*
433	182.70*
443	231.80*
453	265.40*
463	268.40*
473	275.60*

* Not shown in figure.

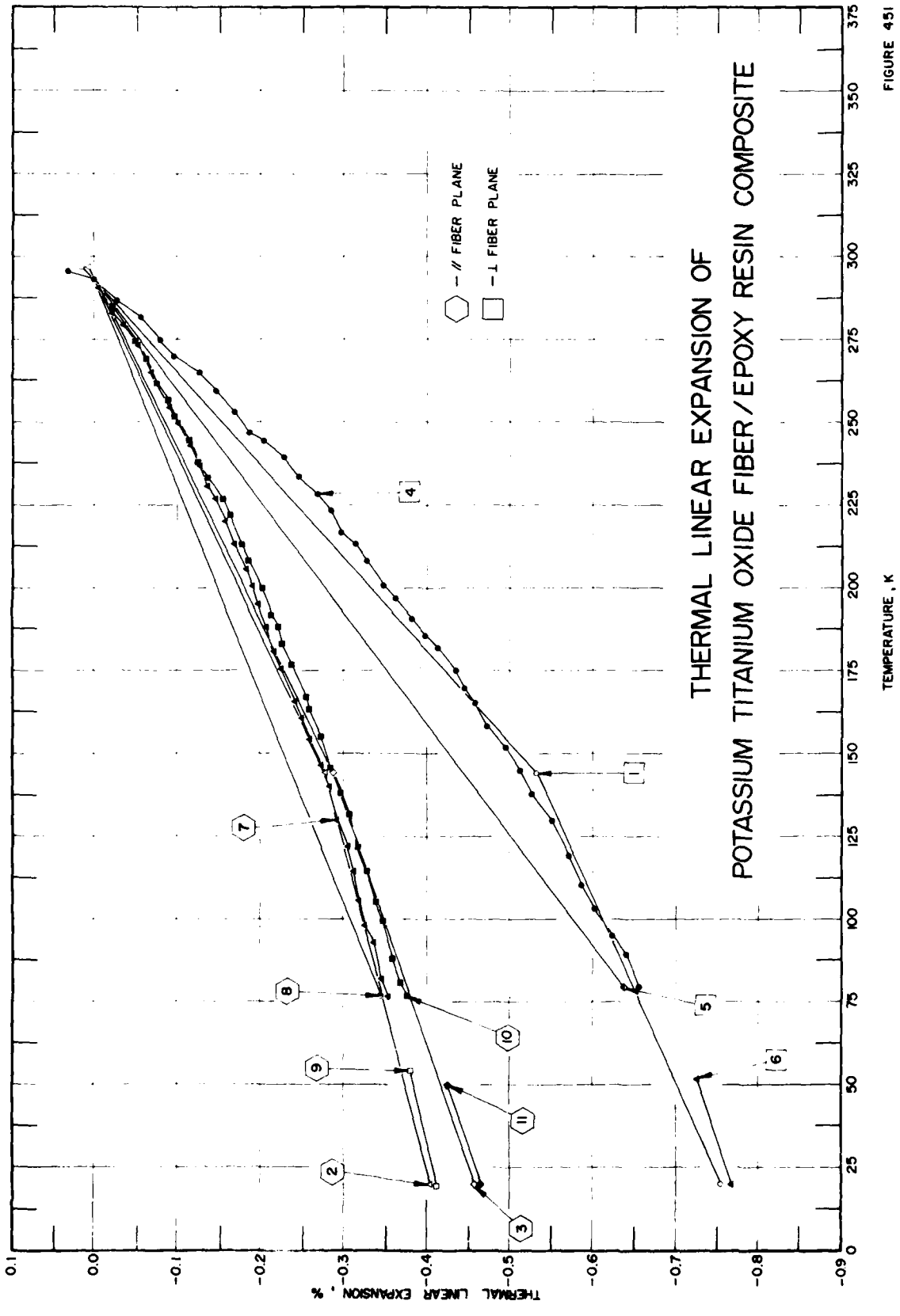

THERMAL LINEAR EXPANSION OF
POTASSIUM TITANIUM OXIDE FIBER / EPOXY RESIN COMPOSITE
// FIBER PLANE
⊥ FIBER PLANE
THERMAL LINEAR EXPANSION, %
TEMPERATURE, K
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
1
2
3
4
5
6
7
8
9
10
11

FIGURE 451

SPECIFICATION TABLE 451. THERMAL LINEAR EXPANSION OF POTASSIUM TITANIUM OXIDE FIBER/EPOXY RESIN COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1057	Campbell, M.D., Haskins, S.F., O'Barr, G.L., and Hertz, J.	1967	L	20-297	T	70.0 potassium titanate fiber, ≤30.0 Epon 828 epoxy resin; specimen dimension 0.5 x 10 x 14 in.; expansion measured in helium atmosphere along thickness of specimen; zero-point correction 0.014%.
2	1057	Campbell, M.D., et al.	1967	L	20-297		The above specimen; expansion measured in 10 in. dimension; zero-point correction 0.007%.
3	1057	Campbell, M.D., et al.	1967	L	20-297		The above specimen; expansion measured in 14 in. dimension; zero-point correction 0.007%.
4	1058	Campbell, M.D., O'Barr, G.L., Haskins, J.F., and Hertz, J.	1965	L	79-296	T	70.0 Tipersul, potassium titanate fibers, 30.0 Epon 828 epoxy resin; composite system by CTL, Div. of Studebaker Corp., resin from Shell Chemical Corp., cured in DTA; specimen is random molding of fibers in resin, pressed to 14 in. x 10 in. x 0.5 in. thick, heated at 200 F for 1 hr; specimen cut from large sample; data given average of results on two similar specimens; expansion measured along thickness of specimen; zero-point correction 0.031%.
5	1058	Campbell, M.D., et al.	1965	L	79,293		The above specimen; expansion measured during second and third cycle.
6	1058	Campbell, M.D., et al.	1965	L	20,52		The above specimen; expansion measured with different instrument.
7	1058	Campbell, M.D., et al.	1965	L	77-297		The above specimen; expansion measured in 14 in. direction on second and third cycles; zero-point correction 0.010%.
8	1058	Campbell, M.D., et al.	1965	L	77,293		The above specimen; expansion of virgin material.
9	1058	Campbell, M.D., et al.	1965	L	19,54		The above specimen; expansion measured with different instrument.
10	1058	Campbell, M.D., et al.	1965	L	77-297	T	The above specimen; expansion measured in 10 in. direction; zero-point correction 0.009%.
11	1058	Campbell, M.D., et al.	1965	L	20,50		The above specimen; expansion measured with low-temperature instrument.

DATA TABLE 451. THERMAL LINEAR EXPANSION OF POTASSIUM TITANIUM OXIDE FIBER/EPOXY RESIN COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

T	$\Delta L/L_0$
CURVE 1	
20	-0.754
144	-0.533
297	0.014
CURVE 2	
20	-0.404
144	-0.279
297	0.007
CURVE 3	
20	-0.458
144	-0.288
297	0.007*
CURVE 4	
79	-0.654
89	-0.640
95	-0.623
103	-0.601
111	-0.587
119	-0.571
130	-0.550
138	-0.527
145	-0.513
152	-0.496
158	-0.472
165	-0.459
169	-0.444
175	-0.435
182	-0.413
186	-0.399
191	-0.383
197	-0.363
201	-0.347
208	-0.328
213	-0.313
217	-0.298
223	-0.284
228	-0.269
233	-0.244
239	-0.228
244	-0.202
247	-0.186
253	-0.169

T	$\Delta L/L_0$
CURVE 4 (cont.)	
259	-0.146
265	-0.125
270	-0.096
275	-0.079
282	-0.054
287	-0.027
293	0.000
296	0.031
CURVE 5	
79	-0.637
293	0.000*
CURVE 6	
20	-0.767
52	-0.725
CURVE 7	
77	-0.351
82	-0.344
93	-0.337
98	-0.325
106	-0.319
114	-0.311
122	-0.304
130	-0.291
140	-0.282
147	-0.272
154	-0.259
161	-0.249
166	-0.241
176	-0.224
181	-0.217
188	-0.208
195	-0.197
201	-0.190
206	-0.182
213	-0.169
220	-0.159
227	-0.145
231	-0.136
237	-0.127
243	-0.115
249	-0.100

T	$\Delta L/L_0$
CURVE 7 (cont.)	
254	-0.091
265	-0.068
273	-0.052
279	-0.034
283	-0.022
291	-0.005
297	0.010*
CURVE 8	
77	-0.342
293	0.000*
CURVE 9	
19	-0.411
54	-0.380
CURVE 10	
77	-0.376
81	-0.369
88	-0.359
99	-0.348
105	-0.339
114	-0.329
122	-0.318
132	-0.308
138	-0.298
146	-0.284
155	-0.272
163	-0.259
167	-0.255
177	-0.238
183	-0.226
188	-0.222
192	-0.214
200	-0.201
208	-0.186
213	-0.177
222	-0.162
227	-0.154
233	-0.136
238	-0.125
244	-0.115
252	-0.098
257	-0.090

T	$\Delta L/L_0$
CURVE 10 (cont.)	
262	-0.076
269	-0.063
274	-0.049
279	-0.038*
285	-0.022
291	-0.004*
297	0.009*
CURVE 11	
20	-0.465
50	-0.425

* Not shown in figure.

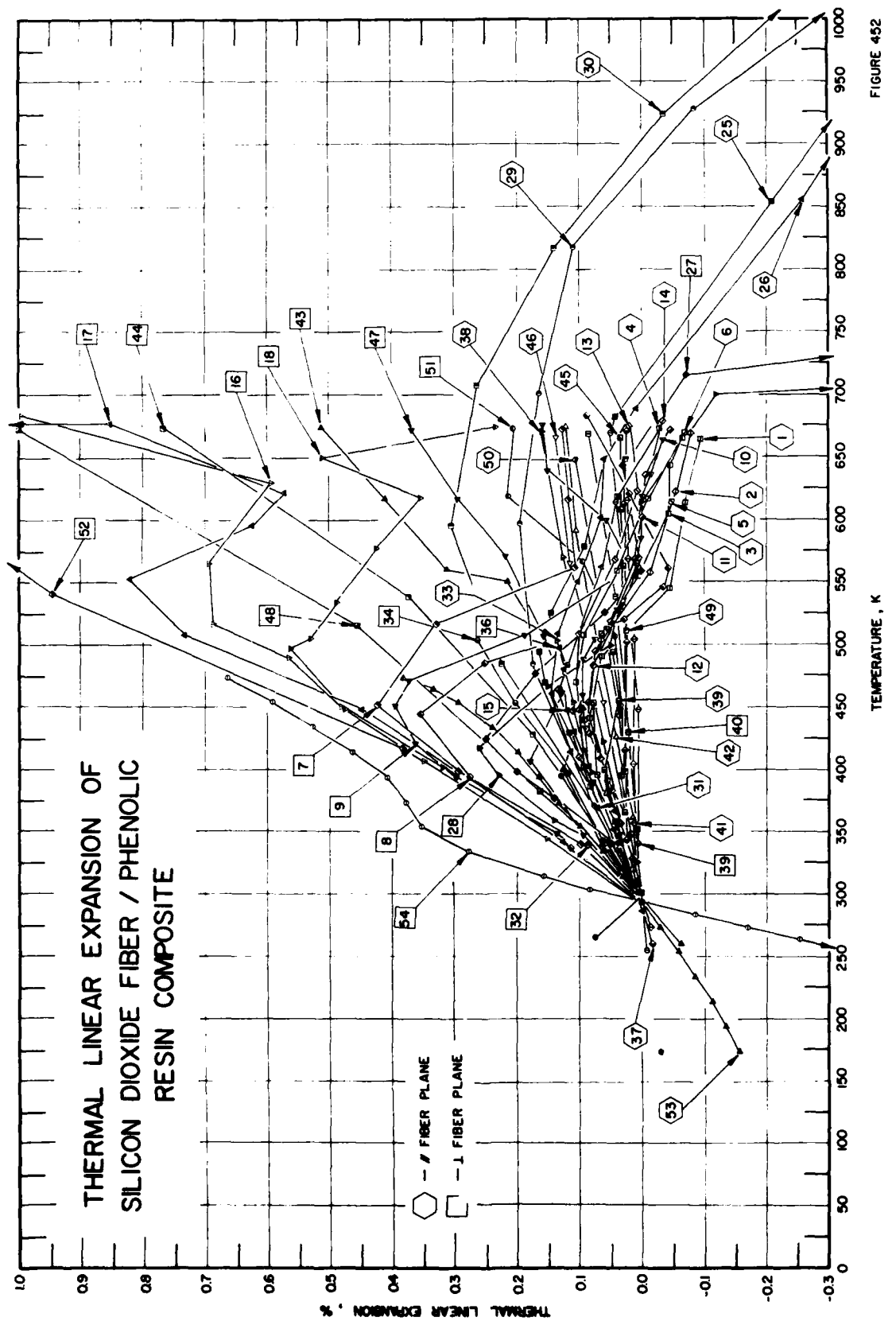

THERMAL LINEAR EXPANSION OF
SILICON DIOXIDE FIBER / PHENOLIC
RESIN COMPOSITE
// FIBER PLANE
⊥ FIBER PLANE
THERMAL LINEAR EXPANSION , %
TEMPERATURE , K

FIGURE 452

SPECIFICATION TABLE 452. THERMAL LINEAR EXPANSION OF SILICONE DIOXIDE FIBER/PHENOLIC RESIN COMPOSITE

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
1	1055	Pears, C.D., Engelke, W.T., and Thornburgh, J.D.	1965	L	293-663	MX 2600 Specimen 1	66% HITCO-C-100-48 or Havoc Sil Temp 84 silica fabric, 8 harness satin weave; 13 plies/0.64 cm, warp aligned; 34% MIL-R-9299 Type II, class 2 phenolic resin with 5-10% silica filler; program cured to 350 F and 200 psi for 6.5 hr; fabricated by Rohr Corp., expansion measured in warp direction; initial length 3.0041 in; reported error ±5%.
2	1055	Pears, C.D., et al.	1965	L	293-669	MX 2600 Specimen 2	Similar to the above specimen; initial length 2.9980 in.
3	1055	Pears, C.D., et al.	1965	L	293-665	MX 2600 Specimen 3	Similar to the above specimen; initial length 3.0032 in.
4	1055	Pears, C.D., et al.	1965	L	294-673	MX 2600 Specimen 1	Similar to the above specimen; expansion measured in fill direction; initial length 3.0020 in.
5	1055	Pears, C.D., et al.	1965	L	294-667	MX 2600 Specimen 2	Similar to the above specimen; initial length 3.0016 in.
6	1055	Pears, C.D., et al.	1965	L	294-669	MX 2600 Specimen 3	Similar to the above specimen; initial length 3.0020 in.
7	1055	Pears, C.D., et al.	1965	L	293-671	MX 2600 Specimen 1	Similar to the above specimen; expansion measured across lamina; initial length 3.0045 in.
8	1055	Pears, C.D., et al.	1965	L	293-682	MX 2600 Specimen 2	Similar to the above specimen; initial length 3.0022 in.
9	1055	Pears, C.D., et al.	1965	L	293-675	MX 2600 Specimen 3	Similar to the above specimen; initial length 3.0028 in.
10	1055	Pears, C.D., et al.	1965	L	293-663	FM 5131 Specimen 1	68% HITCO's C-100-48 Refrasil or Haveg's Sil-Temp 84 silica fabric; 8 harness satin weave, 10 plies/0.64 in.; warp aligned; 32% MIL R 9299 elastomer modified, silica filled phenolic resin; program cured to 16 hr at 65-75 psi and 310 F; fabricated by Thompson Ramo Wooldridge Inc.; expansion measured in warp direction; initial length 3.0010 in.; reported error ±5%.
11	1055	Pears, C.D., et al.	1965	L	293-671	FM 5131 Specimen 2	Similar to the above specimen; initial length 3.0030 in.
12	1055	Pears, C.D., et al.	1965	L	293-670	FM 5131 Specimen 3	Similar to the above specimen; initial length 3.0034 in.
13	1055	Pears, C.D., et al.	1965	L	295-674	FM 5131 Specimen 1	Similar to the above specimen; expansion measured in fill direction; initial length 3.0030 in.
14	1055	Pears, C.D., et al.	1965	L	295-679	FM 5131 Specimen 2	Similar to the above specimen; initial length 3.0030 in.
15	1055	Pears, C.D., et al.	1965	L	295-674	FM 5131 Specimen 3	Similar to the above specimen; initial length 3.0034 in.
16	1055	Pears, C.D., et al.	1965	L	294-682	FM 5131 Specimen 1	Similar to the above specimen; expansion measured across lamina; initial length 3.0055 in.
17	1055	Pears, C.D., et al.	1965	L	294-676	FM 5131 Specimen 2	Similar to the above specimen; initial length 3.0057 in.
18	1055	Pears, C.D., et al.	1965	L	294-673	FM 5131 Specimen 3	Similar to the above specimen; initial length 3.0159 in.

SPECIFICATION TABLE 452. THERMAL LINEAR EXPANSION OF SILICONE DIOXIDE FIBER/PHENOLIC RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
19	1080	Legg, J.K., Sanders, H.G., Engelke, W.T., and Pears, C.D.	1972	L	297-928	II-TEC-1 3DQP	Orthogonal 3DQP specimen containing Monsanto SC1008 resin and Astroquartz roving from J. P. Stevens; supplied by Avco; 9 in. O.D.-7.8 in. I.D.-14 in. long specimen; density 1.662 g cm^{-3}; initial and final weights of specimen 18.9899 gm and 18.9768 gm respectively; initial and final lengths of specimen 3.0046 in. and 3.0030 in. respectively; thermal expansion in circumferential direction; heating rate 4 F/min; instability temperature 372 K.
20	1080	Legg, J.K., et al.	1972	L	297-922	II-TEC-2 3DQP	Similar to the above specimen; initial and final weights of specimen 18.9478 gm and 18.9620 gm respectively; initial and final lengths 3.0046 in. and 3.0023 in. respectively; thermal expansion in circumferential direction; instability temperature 372 K.
21	1080	Legg, J.K., et al.	1972	L	296-923	II-TER-1 3DQP	Similar to the above specimen; density 1.656 g cm^{-3}; initial and final weights of specimen 19.5102 gm and 17.0908 gm respectively; initial and final lengths of specimen 2.9437 in. and 2.9396 in. respectively; thermal expansion in radial direction of cylinder.
22	1080	Legg, J.K., et al.	1972	L	296-934	II-TER-2 3DQP	Similar to the above specimen; density 1.654 g cm^{-3}; initial and final weights of specimen 19.7102 gm and 17.3245 gm respectively; initial and final lengths of specimen 2.9785 in. and 2.9702 in. respectively; thermal expansion in radial direction.
23	1080	Legg, J.K., et al.	1972	L	296-935	II-TEA-1 3DQP	Similar to the above specimen; density 1.666 g cm^{-3}; initial and final weights 19.7109 gm and 17.3915 gm respectively; initial and final lengths 2.9973 in. and 2.9969 in. respectively; thermal expansion in the axial direction of cylinder.
24	1080	Legg, J.K., et al.	1972	L	296-931	II-TEA-2 3DQP	Similar to the above specimen; density 1.673 g cm^{-3}; initial and final weights 19.9994 gm and 17.5955 gm respectively; initial and final lengths 3.0006 in. and 2.9996 in. respectively; thermal expansion in the axial direction of cylinder.
25	1078	Roetling, J. and Hanson, J.	1972	L	293-1317	MX 2600 Phenolic Refrasil	Specimen of flat lay-up material consisted of layers of silica fiber fabric impregnated with a phenolic resin; density 1.71 g cm^{-3}; material shows significant heating rate effects; heating rate 3.6 F/min; first run; measurements with lamina.
26	1078	Roetling, J. and Hanson, J.	1972	L	286-1270	MX 2600 Phenolic Refrasil	The above specimen; second run.
27	1078	Roetling, J. and Hanson, J.	1972	L	293-1343	MX 2600 Phenolic Refrasil	Similar to the above specimen; heating rate 3.6 F/min; measurements across lamina; first run.
28	1078	Roetling, J. and Hanson, J.	1972	L	293-1381	MX 2600 Phenolic Refrasil	The above specimen; second run.
29	1078	Roetling, J. and Hanson, J.	1972	L	293-1814	MX 2600 Phenolic Refrasil	Similar to the above specimen; heating rate 600 F/min; measurements with lamina.

SPECIFICATION TABLE 452. THERMAL LINEAR EXPANSION OF SILICONE DIOXIDE FIBER/PHENOLIC RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
30	1078	Roetling, J. and Hanson, J.	1972	L	293-1814	MX 2600 Phenolic Refrasil	Similar to the above specimen; heating rate 1500 F/min; measurements with lamina.
31	1081	Reiling, H. E.	1964		297-369	R-5 Phenolic Refrasil	A sample billet of the ablative material obtained from the Reinhold Engineering Co. through Rocketdyne; billet fabricated from Sil Temp-84 high silica glass cloth impregnated with SC1008 unfilled resin per Rocketdyne material specification RB0130-011; cured at 320 F and post cured at 420 F; measurements parallel to specimen centerline; resin content 29.95 wt.%; specific gravity 1.756.
32	1081	Reiling, H. E.	1964		297,339	R-5 Phenolic Refrasil	Similar to the above specimen; measurements perpendicular to the specimen centerline.
33	1081	Reiling, H. E.	1964		296-503	R-6 Phenolic Refrasil	Similar to the above specimen; post cured 24 hr at 500 F; measurements parallel to specimen centerline.
34	1081	Reiling, H. E.	1964		296-503	R-9 Phenolic Refrasil	Similar to the above post cured specimen; measurements perpendicular to specimen centerline.
35	1081	Reiling, H. E.	1964		296-494	R-7 Phenolic Refrasil	Similar to the specimen from curve 7; pyrolized; measurements parallel to the specimen centerline.
36	1081	Reiling, H. E.	1964		296-497	R-10 Phenolic Refrasil	Similar to the above pyrolized specimen; measurements perpendicular to the specimen centerline.
37	1065	Pears, C.D., Engelke, W.T., and Thornburgh, J.D.	1964	L	260-670	b-1 Phenolic Refrasil	Phenolic-silica; specific gravity 1.80; 30% (27% after cure) Monsanto SC1008; silica (quartz) fabric from G.E.; void content 17 vol.%; resin molded at 275 F; fabric designation U.S. Polymerics-581-A1100 Quartz SC1008; A1100 finish; lay-up parallel, 26 plies; 181 style; cured at 325 F, 2000 psi for 30 min; initial and final lengths 3.001 in. and 2.996 in. respectively; measurements in the parallel to the reinforcement direction; heating cycle.
38	1065	Pears, C.D., et al.	1964	L	670-296	Phenolic Refrasil	The above specimen and conditions; cooling cycle.
39	1065	Pears, C.D., et al.	1964	L	255-668	Phenolic Refrasil	The above specimen and conditions; initial and final lengths 2.916 in. and 2.900 in. respectively; measurements in the thickness direction; heating cycle.
40	1065	Pears, C.D., et al.	1964	L	668-296	Phenolic Refrasil	The above specimen and conditions; cooling cycle.
41	1065	Pears, C.D., et al.	1964	L	274-674	b-2 Phenolic Refrasil	Similar to the above specimen and conditions; resin content 20% and 28 vol.% void content; measurements in the parallel to reinforcement direction; initial and final lengths 3.003 in. and 3.001 in. respectively; heating cycle.
42	1065	Pears, C.D., et al.	1964	L	674-293	Phenolic Refrasil	The above specimen and conditions; cooling cycle.
43	1065	Pears, C.D., et al.	1964	L	260-673	Phenolic Refrasil	Similar to the above specimen and conditions; measurements in the thickness direction; initial and final lengths 2.937 in. and 2.930 in. respectively; heating cycle.

SPECIFICATION TABLE 452. THERMAL LINEAR EXPANSION OF SILICONE DIOXIDE FIBER/PHENOLIC RESIN COMPOSITE (continued)

Cur. No.	Ref. No.	Author(s)	Year	Method Used	Temp. Range, K	Name and Specimen Designation	Composition (weight percent), Specifications, and Remarks
44	1065	Pears, C.D., et al.	1964	L	673-293	Phenolic Refrasil	The above specimen and conditions; cooling cycle.
45	1065	Pears, C.D., et al.	1964	L	274-665	b-3 Phenolic Refrasil	Similar to the above specimen; specific gravity 1.73; resin content 29.9% (26.0 at.% after cure); void 17 vol.%; CTL-91LD phenolic resin molded at 275 F; quartz fabric of A1100 finish from G.E.; 26 plies; 181 style; cured at 325 F, 2000 psi for 1 hr; initial and final lengths 3.002 in. and 2.999 in. respectively; measurements in the parallel to reinforcement direction; heating cycle.
46	1065	Pears, C.D., et al.	1964	L	665-296	b-3 Phenolic Refrasil	The above specimen and conditions; cooling cycle.
47	1065	Pears, C.D., et al.	1964	L	299-671	b-3 Phenolic Refrasil	Similar to the above specimen and conditions; measurements in the thickness direction; initial and final lengths 2.924 in. and 2.907 in. respectively; heating cycle.
48	1065	Pears, C.D., et al.	1964	L	671-382	b-3 Phenolic Refrasil	The above specimen and conditions; cooling cycle.
49	1065	Pears, C.D., et al.	1964	L	259-648	b-4 Phenolic Refrasil	Similar to the above specimen and conditions; resin content 20%; void content 25 vol.%; measurements in the parallel to reinforcement direction; initial and final lengths 3.001 in. and 2.998 in. respectively; heating cycle.
50	1065	Pears, C.D., et al.	1964	L	648-296	Phenolic Refrasil	The above specimen and conditions; cooling cycle.
51	1065	Pears, C.D., et al.	1964	L	265-672	Phenolic Refrasil	Similar to the above specimen and conditions; measurements in the thickness direction; initial and final lengths 2.926 in. and 2.904 in. respectively; heating cycle.
52	1065	Pears, C.D., et al.	1964	L	672-417	Phenolic Refrasil	The above specimen and conditions; cooling cycle.
53	171	Assay, J.R., Urzendowski, S.R., and Guenther, A.H.	1968	L	173-473	OTWR	Specimen made from 35 wt.% Monsanto SC1008 phenolic resin laminated with 65 wt.% high silica leached glass fabric; reinforcement contains 0.023 B; tape lay-up is at angle of 23 deg; density 1.54 g cm^{-3}; porosity 6.29%; measurements in the parallel to plane direction.
54	171	Assay, J.R., et al.	1968	L	173-473	OTWR	The above specimen; measurements in the perpendicular to the plane direction.
55	171	Assay, J.R., Urzendowski, S.R., and Guenther, A.H.	1968	L	273-473	RAD-60	Polymer is black carbonaceous rigid; density 1.41 g cm^{-3}; measurements in parallel plane direction which is higher than the one in perpendicular plane may be due to layered structure.
56	171	Assay, J.R., et al.	1968	L	273-473	RAD-60	The above specimen; expansion in the perpendicular plane.

DATA TABLE 452. THERMAL LINEAR EXPANSION OF SILICONE DIOXIDE FIBER/PHENOLIC RESIN COMPOSITE

[Temperature, T, K; Linear Expansion, $\Delta L/L_0$, %]

CURVE 1

T	$\Delta L/L_0$
293	0.000*
320	0.016
376	0.057
441	0.084
490	0.066
512	-0.013*
545	-0.043
613	-0.069
663	-0.093

CURVE 2

T	$\Delta L/L_0$
293	0.000*
341	0.037*
396	0.083*
448	0.100
504	0.064
558	-0.012
622	-0.052
669	-0.079

CURVE 3

T	$\Delta L/L_0$
293	0.000*
337	0.030*
391	0.057
440	0.094
505	0.066*
555	0.007
605	-0.042
644	-0.048
665	-0.064

CURVE 4

T	$\Delta L/L_0$
294	0.000*
334	0.036*
344	0.044*
386	0.083
402	0.093
470	0.106
507	0.093
565	0.033*
618	0.040
673	-0.029

CURVE 5

T	$\Delta L/L_0$
294	0.000*
341	0.040*
396	0.073
453	0.079
454	0.034*
557	-0.015*
614	-0.048
667	-0.079*

CURVE 6

T	$\Delta L/L_0$
294	0.000*
346	0.046
404	0.083*
448	0.093*
508	0.066
559	0.040
616	-0.009
669	-0.065

CURVE 7

T	$\Delta L/L_0$
293	0.000*
339	0.098
398	0.294
451	0.423
516	0.329
561	0.107
615	0.117
671	0.127

CURVE 8

T	$\Delta L/L_0$
293	0.000*
336	0.112
394	0.276
445	0.352
485	0.251
520	0.028
546	-0.033
561	-0.042
620	0.020
682	0.088

CURVE 9

T	$\Delta L/L_0$
293	0.000*
349	0.139
394	0.298
420	0.362
45	0.395
471	0.374
507	0.188
557	0.017*
599	0.056
639	0.150
675	0.159

CURVE 10

T	$\Delta L/L_0$
293	0.000*
347	0.037
398	0.073*
433	0.090
458	0.093
487	0.093
503	0.073
512	0.057
528	0.039
549	0.020*
563	0.010
585	0.000
617	-0.002
636	-0.016
663	-0.036

CURVE 11

T	$\Delta L/L_0$
293	0.000*
328	0.017
356	0.037
374	0.050*
398	0.063*
429	0.083
454	0.086
494	0.076
518	0.050
551	0.030*
568	0.014
602	0.000
636	-0.006
671	-0.046

CURVE 12

T	$\Delta L/L_0$
293	0.000*
342	0.030*
383	0.050
408	0.067
444	0.083*
482	0.079
531	0.030
570	0.007
618	-0.006*
670	-0.042*

CURVE 13

T	$\Delta L/L_0$
295	0.000*
337	0.031*
397	0.077*
447	0.110
508	0.100
508	0.080*
568	0.041
622	0.008
674	0.020

CURVE 14

T	$\Delta L/L_0$
295	0.000*
339	0.040*
410	0.100
463	0.133
508	0.090*
562	0.034*
615	-0.008*
679	-0.032

CURVE 15

T	$\Delta L/L_0$
295	0.000*
351	0.047
404	0.094*
430	0.110
447	0.120
481	0.124
484	0.120
562	0.064
620	0.040*
674	-0.002*

CURVE 16

T	$\Delta L/L_0$
294	0.000*
344	0.151
406	0.349
450	0.481
489	0.567
516	0.687
565	0.693
629	0.594
682	0.997

CURVE 17

T	$\Delta L/L_0$
294	0.000*
341	0.126
396	0.296*
448	0.449
507	0.734
552	0.823
595	0.626
621	0.575
672	1.113*
676	0.851

CURVE 18

T	$\Delta L/L_0$
294	0.000*
401	0.318
448	0.476
496	0.563
504	0.530
534	0.489
577	0.422
617	0.363
650	0.511
673	0.233

CURVE 19*

T	$\Delta L/L_0$
297	0.003
336	0.019
378	0.026
400	0.020
451	0.012
468	0.012
494	0.013
510	0.013

CURVE 19 (cont.)*

T	$\Delta L/L_0$
534	0.013
560	0.015
656	0.024
790	-0.018
928	-0.040

CURVE 20*

T	$\Delta L/L_0$
297	0.001
398	0.016
428	0.006
445	0.007
460	0.009
507	0.018
550	0.024
561	0.020
574	0.021
658	0.032
786	-0.022
922	-0.031

CURVE 21*

T	$\Delta L/L_0$
296	0.003
329	0.026
371	0.040
395	0.026
451	-0.023
456	-0.025
501	0.013
550	0.030
576	0.027
621	0.033
673	-0.001
805	-0.147
923	-0.160

CURVE 22*

T	$\Delta L/L_0$
296	0.004
334	0.034
373	0.046
400	0.014
453	-0.022
480	-0.022
513	-0.018

* Not shown in figure.

DATA TABLE 452. THERMAL LINEAR EXPANSION OF SILICONE DIOXIDE FIBER/PHENOLIC RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 22 (cont.)	
551	-0.012
567	-0.022
578	-0.026
616	-0.020
674	-0.071
794	-0.182
914	-0.221
934	-0.220
CURVE 23*	
296	0.003
331	0.020
369	0.027
394	0.014
438	0.001
452	0.003
505	0.020
558	0.025
583	0.026
640	0.036
669	0.037
820	-0.003
935	-0.010
CURVE 24*	
296	0.002
332	0.022
372	0.026
394	0.017
450	-0.003
461	-0.002
510.94	0.015
556	0.020
566	0.019
572	0.017
646	0.032
672	0.028
795	-0.013
885	-0.016
931	-0.002
CURVE 25	
293	0.000
300	0.000
357	0.042
389	0.079
429	0.116
469	0.155
493	0.163
525	0.145
579	0.091
681	0.042
854	-0.209
1015	-0.444*
1166	-0.753*
1317	-1.347*
CURVE 26	
286	0.000
293	0.000*
340	0.033
414	0.114
460	0.145
508	0.135
550	0.101
601	0.064
647	0.060
684	0.009
855	-0.257
1017	-0.484*
1170	-1.093*
1270	-1.461*
CURVE 27	
293	0.000*
300	0.000*
340	0.050
376	0.140
398	0.200
424	0.250
476	0.170
525	0.060
559	0.000
643	0.030
715	-0.070
738	-0.590*
821	-0.880*
872	-3.770*
934	-1.420*
1013	-4.850*
1159	-5.280*
1310	-5.840*
1343	-6.210*
CURVE 28	
293	0.000*
300	0.000*
325	0.080
358	0.140
395	0.230
417	0.260
466	0.150
499	0.050
613	0.000
699	-0.120
746	-1.150*
788	-2.590*
856	-3.410*
923	-4.260*
1006	-4.730*
1161	-5.100*
1314	-5.750*
1381	-6.040*
CURVE 29	
293	0.000*
300	0.007
370	0.078
484	0.173
596	0.197
700	0.165
817	0.110
927	-0.082
1032	-0.425*
1150	-0.726*
1254	-1.091*
1372	-1.524*
1481	-1.934*
1589	-2.088*
1699	-2.088*
1814	-1.810*
CURVE 30	
293	0.000*
300	0.000*
368	0.079*
485	0.224
595	0.303
706	0.263
816	0.140
927	-0.035
1035	-0.275*
1149	-0.551*
1256	-0.974*
1370	-1.381*
1483	-1.606*
1592	-1.728*
CURVE 31	
297	0.004*
341	0.040
369	0.074
CURVE 32	
297	0.008*
339	0.088
CURVE 33	
296	0.002*
342	0.039*
398	0.080
453	0.110
503	0.137
CURVE 34	
296	0.004*
342	0.062
398	0.119
453	0.202
503	0.264
CURVE 35	
296	0.003*
342	0.045
366	0.028
400	0.060
455	0.039
494	0.048
CURVE 36	
296	0.003*
342	0.047*
366	0.047
402	0.085
455	0.097
497	0.133
CURVE 37	
260	-0.016
295	-0.001*
295	0.004*
342	0.024
415	0.028
450	0.024*
501	0.024
560	0.026*
612	0.028
670	0.025
CURVE 38	
670	0.159
570	0.125
422	0.062
296	0.002*
CURVE 39	
255	-0.006
295	0.000*
340	0.006
394	0.015*
448	0.008
504	0.018*
559	0.027*
614	0.042
668	0.050
CURVE 40	
668	0.085
539	0.041
430	0.022
352	0.009
296	0.002*
CURVE 41	
274	-0.012
295	0.001*
356	0.012
403	0.013
449	0.011*
504	0.014
568	0.021
615	0.026
674	0.026*
CURVE 42	
674	0.122
592	0.103
426	0.041
361	0.017
293	0.000*
CURVE 43	
260	-0.061
293	0.000*
393	0.008*
339	0.064
400	0.127
449	0.094
550	0.216
560	0.311
616	0.411
673	0.513
CURVE 44	
673	0.769
538	0.373
427	0.177
340	0.057
293	0.000*
CURVE 45	
274	-0.010*
298	0.003*
348	0.019
395	0.031
452	0.029*
501	0.029*
563	0.030

* Not shown in figure.

DATA TABLE 452. THERMAL LINEAR EXPANSION OF SILICONE DIOXIDE FIBER/PHENOLIC RESIN COMPOSITE (continued)

T	$\Delta L/L_0$
CURVE 45 (cont.)	
608	0.032
665	0.032
CURVE 46	
665	0.138
565	0.115
453	0.062
344	0.019
296	0.002*
CURVE 47	
299	0.001*
299	0.009*
346	0.093
406	0.179
460	0.128
506	0.158
570	0.217
616	0.294
671	0.369
CURVE 48	
671	1.000
515	0.456
382	0.164
CURVE 49	
259	-0.0189*
274	-0.0124*
298	0.0008*
338	0.0106*
399	0.0287
457	0.0247*
511	0.0276
560	0.0280*
644	0.0307*
648	0.0278
CURVE 50	
648	0.1061
443	0.0394
350	0.0091*
296	0.0008*
CURVE 51	
265	0.0750
296	0.0087*
296	-0.0072*
340	0.0563*
395	0.1307
452	0.0353
506	0.0444
566	0.0967
618	0.2151
672	0.2066
CURVE 52	
672	1.2646*
540	0.9461
417	0.3838
CURVE 53‡	
173	-0.158
183	-0.146*
193	-0.135
203	-0.123*
213	-0.112
223	-0.099*
233	-0.086
243	-0.074*
253	-0.059
263	-0.043*
273	-0.028
283	-0.014*
293	0.000*
303	0.015*
313	0.030
323	0.045*
333	0.062
343	0.080*
353	0.099
363	0.116*
373	0.132
383	0.149*
393	0.165
403	0.181*
413	0.199
423	0.219*
433	0.240
443	0.265*
453	0.295
CURVE 53 (cont.)‡	
463	0.334
473	0.382
CURVE 54‡	
173	-0.864*
183	-0.804*
193	-0.743*
203	-0.681*
213	-0.616*
223	-0.549*
233	-0.479*
243	-0.408*
253	-0.333*
263	-0.253
273	-0.170
283	-0.085
293	0.000*
303	0.082
313	0.158
323	0.223*
333	0.276
343	0.319*
353	0.351
363	0.368*
373	0.378
383	0.391*
393	0.409
403	0.434*
413	0.463
423	0.495*
433	0.528
443	0.562*
453	0.592
463	0.624*
473	0.665
CURVE 55‡	
273	-0.004
283	-0.002*
293	0.000*
303	0.001*
313	0.003
323	0.003*
333	0.004
343	0.006*
353	0.007*
CURVE 55 (cont.)‡	
363	0.010*
373	0.014
383	0.019*
393	0.026*
403	0.035*
413	0.047
423	0.061*
433	0.078*
443	0.096
453	0.115*
463	0.138*
473	0.162
CURVE 56‡	
273	0.008*
283	0.004
293	0.000*
303	-0.004*
313	-0.008*
323	-0.012
333	-0.016*
343	-0.020*
353	-0.024
363	-0.028*
373	-0.031*
383	-0.034
393	-0.037*
403	-0.040
413	-0.042*
423	-0.044*
433	-0.046*
443	-0.048
453	-0.049*
463	-0.049*
473	-0.049

* Not shown in figure.
‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

DATA TABLE 452. COEFFICIENT OF THERMAL LINEAR EXPANSION OF SILICONE DIOXIDE FIBER/PHENOLIC RESIN COMPOSITE

[Temperature, T, K; Coefficient of Expansion, α, 10^{-6} K^{-1}]

T	α
CURVE 53‡	
173	11.40
183	10.70
193	12.10
203	11.40
213	12.10
223	13.10
233	12.70
243	12.40
253	16.40
263	15.40
273	15.10
283	13.10
293	14.70
303	14.70*
313	15.00*
323	15.00*
333	19.10*
343	18.40*
353	18.10*
363	16.80*
373	16.10*
383	16.80*
393	15.40*
403	16.40*
413	19.10*
423	21.40*
433	21.40*
443	27.20*
453	33.50*
463	43.70*
473	53.60*
CURVE 54‡	
173	60.00
183	60.10
193	62.00
203	62.00
213	66.60
223	69.00
233	70.00
243	72.00
253	77.60
263	82.50
273	83.60
283	86.90
293	83.00
303	80.20*
313	73.50*
323	55.40*
333	50.10*
343	36.80*
353	26.70*
363	6.70*
373	13.40*
383	13.40*
393	23.40*
403	26.70*
413	30.10*
423	33.40*
433	33.00*
443	35.00*
453	25.60*
463	37.90*
473	43.50*
CURVE 55	
273	2.020
283	1.790
293	1.520
303	1.250
313	1.020
323	0.910
333	1.020
343	1.430
353	1.990
363	3.030
373	4.390
383	6.080
393	8.080
403	10.429
413	12.449
423	16.160
433	17.500
443	18.890
453	20.199
463	24.210
473	25.400
CURVE 56	
273	-3.830
283	-3.950
293	-4.000
303	-4.010
313	-4.100
323	-4.050
333	-4.000
343	-3.900
353	-3.760
363	-3.560
373	-3.360
383	-3.060
393	-2.850
403	-2.580
413	-2.200
423	-1.900
433	-1.530
443	-1.580
453	-0.650
463	-0.250
473	0.050

* Not shown in figure.

‡ Author's data for coefficient of thermal expansion have been integrated by TPRC to obtain $\Delta L/L_0$.

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Beryllium Be	12	24
Beryllium Alloy, Lockalloy	12	1057, 1059
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Beryllium Bronze	12	679
Beryllium-Copper System	12	678
Beryllium-Hafnium Intermetallic Compound β-$Be_{17}Hf_2$	12	461
Beryllium-Iron System	12	680
Beryllium-Niobium Intermetallic Compound $Be_{12}Nb$	12	464
Beryllium Oxide BeO	13	195
Beryllium Oxide + Beryllium BeO + Be	13	1313
Beryllium Oxide + Beryllium + Molybdenum BeO + Be + Mo	13	1341
Beryllium Oxide + Beryllium + Silicone BeO + Be + Si	13	1341
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$Be_{17}Ta_2$	12	468, 469, 471
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CrB	13	796
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HfB_2	13	758
HoB_{12}	13	763
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LuB_{12}	13	793
MoB_2	13	796
NbB_2	13	767
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SiB_4	13	797
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TaB_2	13	772
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Boron Fiber/Epoxy Resin Composite	13	1531
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Boron Phosphide BP	13	1165
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CuBr	13	838
$PbBr_2$	13	806
LiBr	13	836
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KBr	13	810
KBr + KCl	13	830
KBr + RbBr	13	838
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RbBr + RbCl	13	834
AgBr	13	836
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Cadmium Selenide CdSe	13	1185
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Cadmium Telluride CdTe	13	1243
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Cadmium Tin Arsenide $CdSnAs_2$	13	752
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Cadmium Zirconium Oxide $CdO \cdot ZrO_2$	13	602
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Calcium Aluminum Iron Oxide $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$	13	509
Calcium Aluminum Oxide $CaO \cdot Al_2O_3$	13	464
Calcium Aluminum Oxide $CaO \cdot 6Al_2O_3$	13	468
Calcium Aluminum Oxide $3CaO \cdot Al_2O_3$	13	469
Calcium Aluminum Oxide $3CaO \cdot 5Al_2O_3$	13	473
Calcium Aluminum Oxide $5CaO \cdot 3Al_2O_3$	13	474
Calcium Aluminum Silicate $Ca_2Al_2SiO_7$	13	727
Calcium Dialuminum Orthosilicate $CaAl_2(SiO_4)_2$	13	707
Calcium Borate Glass $CaO-B_2O_3$	13	1358
Calcium Carbonate $CaCO_3$	13	637
Calcium Feldspar	13	707
Calcium Fluoride CaF_2	13	1025
Calcium Hafnium Oxide $CaO \cdot HfO_2$	13	501
Calcium Iron Oxide $CaO \cdot Fe_2O_3$	13	503
Calcium Iron Oxide $2CaO \cdot Fe_2O_3$	13	506
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Calcium Magnesium Orthosilicate $CaMgSiO_4$	13	708
Calcium Magnesium Metasilicate $CaMg(SiO_3)_2$	13	708
Dicalcium Magnesium Silicate $Ca_2MgSi_2O_7$	13	708
Tricalcium Magnesium Orthosilicate $Ca_3Mg(SiO_4)_2$	13	708
Calcium Magnesium Tungsten Oxide $2CaO \cdot MgO \cdot WO_3$	13	584
Calcium Molybdenum Oxide $CaO \cdot MoO_3$	13	517
Calcium Oxide CaO	13	208
Calcium Silicate Ca_3SiO_5	13	705
Calcium Silicate $Ca_3Si_2O_7$	13	705
Calcium Orthosilicate Ca_2SiO_4	13	705
Calcium Metasilicate $CaSiO_3$	13	705
Calcium Sulfide CaS	13	1239
Calcium Tungsten Oxide $CaO \cdot WO_3$	13	580
Calcium Zirconium Oxide $CaO \cdot ZrO_2$	13	603
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NbC	13	858
PuC	13	866
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SmC_2	13	936
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TiC	13	891
WC	13	898
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TaC	13	879
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ThC	13	937
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UC	13	902
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TaC + WC	13	940
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ZrC + C	13	957
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$CoCO_3$	13	641
$FeCO_3$	13	642
$MgCO_3$	13	643
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$UO_2 + Mo$	13	1326
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CuCl	13	1013
$FeCl_3$	13	1013
$PbCl_2$	13	977
PbFCl	13	1013
LiCl	13	979
$MnCl_2 \cdot 4H_2O$	13	1013
KCl	13	982
KCl + RbCl	13	1012
RbCl	13	990
AgCl	13	995
NaCl	13	1000
$SrCl_2$	13	1014
TlCl	13	1014
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Chromium Diboride CrB_2	13	796
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Trichromium Silicide Cr_3Si	13	1195
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Cobalt Dichloride $CoCl_2 \cdot 6H_2O$	13	1013
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Cobalt-Palladium System	12	747, 752
Cobalt Orthorphosphate $Co_3(PO_4)_2$	13	689
Cobalt-Platinum System	12	754
Cobalt Orthosilicate Co_2SiO_4	13	727
Cobalt Silicide CoSi	13	1211
Tricobalt Silicide Co_3Si	13	1211
Cobalt-Tantalum System	12	755
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Dysprosium Aluminum Garnet	13	476
Dysprosium Aluminum Oxide $Dy_2O_3 \cdot 2Al_2O_3$	13	475
Dysprosium Aluminum Oxide $3Dy_2O_3 \cdot 5Al_2O_3$	13	476
Dysprosium Dodecaboride DyB_{12}	13	793
Dysprosium Carbide DyC_2	13	935
Dysprosium Niobium Oxide $Dy_2O_3 \cdot Nb_2O_5$	13	525
Dysprosium Oxide Dy_2O_3	13	227
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CdF_2	13	1076
CaF_2	13	1025
CsF	13	1076
CoF_2	13	1076
FeF_2	13	1030
LaF_3	13	1032
PbF_2	13	1034
LiF	13	1036
$LiF + NiF_2$	13	1075
MgF_2	13	1043
MnF_2	13	1048
NiF_2	13	1052
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Ytterbium Dihydride YbH_2	13	1091
Ytterbium Oxide Yb_2O_3	13	435
Ytterbium-Zinc Intermetallic Compound $YbZn_2$	12	625
Yttrium Y	12	387
Yttrium Oxide Y_2O_3	13	438
Yttrium Silicate Y_2SiO_5	13	728
Zinc Zn	12	391
Zinc Aluminum Oxide $ZnO \cdot Al_2O_3$	13	485
Zinc Arsenide Zn_3As_2	13	752
Zinc Fluoride ZnF_2	13	1071
Zinc Germanium Oxide $2ZnO \cdot GeO_2$	13	500
Zinc Oxide ZnO	13	444
Zinc Metaphosphate $Zn(PO_3)_2$	13	684
Zinc Orthophosphate $Zn_3(PO_4)_2$	13	681
Zinc Pyrophosphate $Zn_2P_2O_7$	13	691
Zinc Selenide ZnSe	13	1187
Zinc Orthosilicate Zn_2SiO_4	13	722
Zinc Sulfide ZnS	13	1232
Zinc Telluride ZnTe	13	1265
Zinc Vanadium Oxide $ZnO \cdot V_2O_5$	13	598
Zinc Vanadium Oxide $2ZnO \cdot V_2O_5$	13	599
Zinc Vanadium Oxide $3ZnO \cdot V_2O_5$	13	600
Zinc-Zirconium Intermetallic Compound Zn_2Zr	12	628
Zircaloy-2	12	987, 1313
Zircaloy-4	12	1313, 1314
Zirconium Zr	12	400
Zirconium Alloys (specific types)		
Alloy 7	12	1318
Alloy 9	12	1318
Zircaloy-2	12	1313
Zircaloy-4	12	1313, 1314

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Zirconium Diboride ZrB_2	13	784
Zirconium Dodecaboride ZrB_{12}	13	793
Zirconium Diboride + Chromium $ZrB_2 + Cr$	13	1342
Zirconium Diboride + Molybdenum Disilicide + ΣX_i $ZrB_2 + MoSi_2 + \Sigma X_i$	13	790
Zirconium Carbide ZrC	13	926
Zirconium Carbide + Carbon $ZrC + C$	13	957
Zirconium Carbide + Graphite $ZrC + C$	13	964
Zirconium Chromium Oxide $ZrO_2 \cdot Cr_2O_3$	13	490
Zirconium Complex Oxides		
$BaO \cdot ZrO_2$	13	601
$CdO \cdot ZrO_2$	13	602
$CaO \cdot ZrO_2$	13	603
$PbO \cdot ZrO_2$	13	606
$SrO \cdot ZnO_2$	13	611
Zirconium Dihydride ZrH_2	13	1093
Zirconium Nitride ZrN	13	1156
Zirconium Dioxide ZrO_2	13	451
Zirconium Dioxide + Titanium $ZrO_2 + Ti$	13	1333
Zirconium Dioxide + Zirconium $ZrO_2 + Zr$	13	1337
Zirconium Phosphate $Zr_2P_2O_9$	13	687
Zirconium Orthophosphate $ZrPO_4$	13	687
Zirconium Pyrophosphate ZrP_2O_7	13	687
Zirconium Orthosilicate $ZrSiO_4$	13	724
Zirconium Disilicide $ZrSi_2$	13	1214
Zirconium + Tin + ΣX_i	12	1312
Zirconium + Titanium + ΣX_i	12	1317
Zirconium Titanium Oxide $ZrO_2 \cdot TiO_2$	13	574
Zirconium Tungsten Oxide $ZrO_2 \cdot 2WO_3$	13	594
ZTA Graphite	13	107
ZTB Graphite	13	115
ZTC Graphite	13	119
ZTD Graphite	13	128
ZTE Graphite	13	128
ZTF Graphite	13	129